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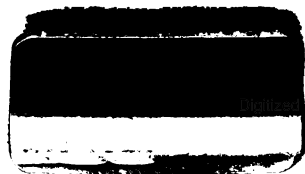
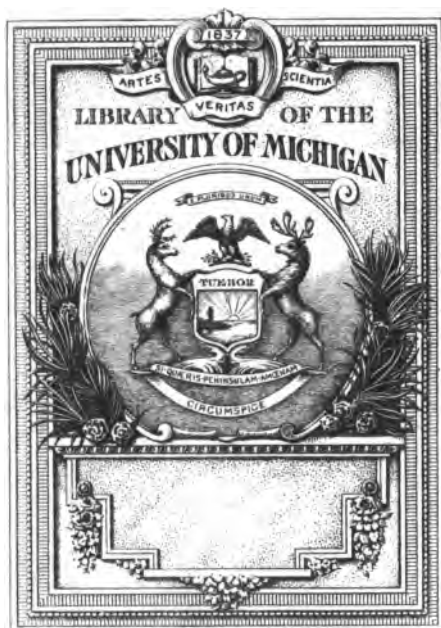
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MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

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ABSTRACT OF THE

Proceedings of the Society of Arts,

WITH LIST OF OFFICERS AND MEMBERS,

FOR THE TWENTY-EIGHTH YEAR.

1889-1890.

MEETINGS 392 TO 404 INCLUSIVE.



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NOTICE.

The SOCIETY OF ARTS, established in conformity with the plan of the Massachusetts Institute of Technology, as set forth in the act of incorporation, April, 1861, held its first meeting on April 8, 1862.

The objects of the Society are to awaken and maintain an active interest in the practical sciences, and to aid generally in their advancement in connection with arts, agriculture, manufactures, and commerce.

Regular meetings are held semi-monthly from October to May, inclusive, in the Institute Building; and at each meeting communications are presented on some subjects germane to the objects of the Society, as stated above.

The present volume contains the abstracts of the communications made during the year ending October 1, 1890, most of the business portions of the records being omitted.

The thanks of the Society are due to Capt. A. H. Russell, for the loan of the electrotypes used in illustrating his paper on Magazine Guns; to Col. E. H. Hewins for those illustrating his paper on Storage Batteries; to the Electrical Engineer for those illustrating Prof. Thomson's paper on "Experiments with Alternating Currents"; to the Engineering and Building Record for those illustrating Mr. Woodbridge's paper on The Heating and Ventilating of the new Engineering Building.

For the opinions advanced by any of the speakers the Society assumes no responsibility.

LINUS FAUNCE,

SECRETARY.

BOSTON, SEPT., 1890.



THE ENGINEERING BUILDING.

PROCEEDINGS OF THE SOCIETY OF ARTS

FOR THE TWENTY-EIGHTH YEAR.

MEETING 392.

*Biological Water Analysis.**

BY PROF. W. T. SEDGWICK.

The 392nd meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, October 10, 1889, at 8 P.M., Hon. J. A. Dresser in the chair.

After the reading of the records of the previous meeting, the Chairman introduced Prof. W. T. Sedgwick, of the Institute, who read a paper on "Biological Water Analysis."

Prof. SEDGWICK said: A biological analysis of water, strictly speaking, is an impossibility. Water may be analyzed chemically and resolved into its components, hydrogen and oxygen, but a biological analysis of water is an impossibility, because water is absolutely lifeless and inorganic. By a chemical "water analysis," however, the chemist does not usually mean the analysis of a portion of pure water, but only a chemical examination of the substances dissolved in, or carried by, the water. In precisely the same way a biological "water analysis" is understood to be simply *an examination of the organisms present in a particular portion of water.*

The biological analysis of a water must deal with all the organisms which can be detected therein; but inasmuch as the coarser water-dwellers — the fishes, the frogs, the snails, the water-weed, etc. — are seldom collected in a sample for water analysis, there are usually present only the very small, and often quite invisible, organ-

* Revised from an address published in the Journal N. E. Water Works Association, September, 1889.

isms which may nevertheless be exceedingly numerous. Practically, therefore, the biological examination is directed to the inconspicuous forms of life, which often swarm in waters, even in those used for drinking. Taken as a whole, these organisms are known as the "microorganisms," and form a vast group of living things, some of them nearly, and some of them quite, beyond the vision of the naked eye. In dealing with the microorganisms in a sample of water, or in a water supply, the coarser organisms must by no means be neglected; but the biological analysis of water as at present conducted is concerned especially with the microorganisms; and in the present paper no great departure will be made from the prevailing point of view.

Microorganisms are of two different kinds, and must be studied in two very different ways. Although all might perhaps be described as "microscopic" in size, those in one group are so much smaller than those in the other as to be almost smaller than "microscopic." These smallest microorganisms are the bacteria; and, although they may be seen by the help of the microscope, and, indeed, can be seen individually in no other way, they cannot be satisfactorily studied — still less counted — by the microscope alone. These organisms — the bacterial — are therefore detected and chiefly studied by the method of "cultures," otherwise known as "Koch's method," which I have already had the honor to describe and demonstrate at a meeting of this Society some two years ago. Of the bacterial microorganisms I shall speak tonight only incidentally, although within that time our knowledge of them and of their doings has been steadily advancing.

On this occasion I desire rather to turn your attention to the second division of the microorganisms, the microscopical. This includes all microorganisms except the bacterial, and is separated from that group by the fact that while the latter require for their satisfactory study the employment of "cultures," the microscopical microorganisms may be detected, counted, and pretty fully studied by the microscope alone.

In a summary fashion the relations of these groups may be shown as follows: —

MICROÖRGANISMS.

Organisms, either plants or animals, too small to be studied with the naked eye.

MICROSCOPICAL ORGANISMS.

Not requiring special "cultures." Easily studied with the microscope. Microscopic in size, or barely visible to the naked eye. Plants or animals.

BACTERIAL ORGANISMS.

Requiring special cultures for their satisfactory study. Difficult of study with the microscope, because almost sub-microscopic in size. Plants.

The bacterial microörganisms include the bacteria, as well as some yeasts and moulds. The microscopical microörganisms include a great variety of animals, such as minute entomostraca, like Cyclops and the water flea; various worms and wheel-animalcules; sponges and the fresh-water Hydra; infusoria, rhizopods, and such like; and among the plants, the diatoms, algæ, fungi (excepting those already mentioned), and the so-called "blue-green algæ." Beside the bacteria these forms are mostly of giant size, and hence may be seen and studied with comparative ease by the aid of the microscope alone.

I am the more anxious to urge upon your attention the microscopical microörganisms since it is with them that some of the more recent progress has been made in the biological analysis of water. Furthermore, it is in this field, in all probability, that some of the most interesting developments of the next year or two will be found. These are the organisms that often pave the way for the bacteria in water, and possibly therefore for the germs of disease. These are the organisms which are, in large measure, the source in water of the "organic nitrogen" (or albuminoid ammonia) of the chemists; the organisms, responsible in large measure, for odors, tastes, and turbidities in waters, either directly by their own activity, or indirectly by amassing organic matter, and eventually surrendering it as putrescible food for the more destructive bacterial organisms.

As long ago as 1850 Dr. Arthur Hill Hassall made a microscopical examination of the water supply of London, perhaps the first ever scientifically made anywhere, and, in discussing his results, wrote afterwards as follows: * "The deleterious properties of impure water depend, for the most part, on their *organic impurities*.

* "Food and its Adulterations," p. 55, London, 1885.

"Until very recently chemists did not, in general, attach sufficient importance to these organic contaminations, and in most of their analyses we find the different kinds of organic matter, vegetable and animal, living and dead, all lumped together and included under the word 'traces.' . . . Indeed, chemistry is but ill-adapted to investigate the nature of these organic matters; it gives but a very rough estimate only of their gross amount, and does not discriminate, as we have said, the animal from the vegetable, the dead from the living, and tells us nothing about the families, genus, and species to which the numerous living productions contained in impure waters severally belong; or of their habits and modes of life," etc.

For twenty years after Dr. Hassall's day his work remained almost alone. In 1870, however, Prof. Cohn, the biologist, of Breslau, in an extremely suggestive paper on the "Microscopical Analysis of Well Waters," perceiving, perhaps, better than anyone else has yet done the profound significance of such studies, wrote as follows: * "There is no doubt that microscopical examinations of drinking-waters, properly conducted, will strengthen and perfect the chemical examinations at the most essential points, and that they only will give us information upon certain questions which the reagents of the chemist cannot answer."

As if to justify his assertion, Cohn immediately proceeds to compare the results of chemical analyses with his own observations of corresponding microscopical conditions, and, as might have been expected, with interesting results. There is even here, however, no prolonged comparison of chemical with biological results, and hence no such fertile outcome as might have been attained.

After Cohn's paper we find nothing so suggestive up to the present day. It stands alone, so far as I know, in a serious and enlightened endeavor to coördinate and render mutually helpful chemical and biological data. With this one brilliant exception, little progress has been made in the interpretation of chemical and microscopical analyses of water (though of the former vast numbers have been accumulated), simply, I believe, because chemists, on the one hand, have been content to name the most complex and the most important substances in their analyses "organic matter," therewith

* "Beiträge zur Biologie," I, 109.

resting satisfied ; while biologists, on the other, instead of seeking a simple explanation for the presence or absence of organisms, or endeavoring to learn their chemical significance, have too often dissipated their energies in struggles to classify those organisms which they could name, and to name those which they could not classify. Doubtless, also, the rise of bacteriology, soon after the appearance of Cohn's paper, with the intense interest which it aroused, did much to distract attention from the microscopical microorganisms, and to fix it upon the bacterial. But even concerning the bacterial microorganisms interest has been thus far principally medical. The discovery that infectious diseases may be propagated in drinking-water caused general alarm. Most bacteria, however, are not disease germs ; and yet they are scarcely less interesting on that account, for by their presence they always signify something, and in their absence are hardly less conspicuous. Bacteria are fungi ; that is, they are not green with chlorophyll, and, consequently, since they cannot build up food for themselves from mineral matters, as they might do if they had chlorophyll, they are obliged to live upon ready-made foods. If, then, a drinking-water contains bacteria, living and thriving, there is no escape from the conclusion that there is or has lately been ready-made food in that water. Well waters usually contain few bacteria ; and this we would expect from their poverty in ready-made food.— which is only another name for some kinds of organic matter. River waters usually contain numerous bacteria, and ready-made food is generally there in the shape of organic matter of one kind or another. Now, it is precisely this ready-made food that the bacteria must live upon, and which they oxidize eventually to mineral matters, that the larger, microscopical, microorganisms abundantly produce. Moreover, the microscopical organisms not only pave the way for bacteria, they often themselves become serious nuisances in reservoirs and lakes used as water supplies, by giving rise to extensive "growths" which, either during their development generate directly odors and tastes, or during their decay support a prolific host of bacteria, thus generating indirectly turbidities or odors which make the water disgusting and unfit to drink. It is somewhat remarkable that while the importance of these organisms and of their accurate study has long been recognized, no satisfactory method has hitherto been devised for their study. Up to the present time the best methods have made no pretensions to be

quantitative, and microscopical examinations of water have been usually directed to the sediment obtained by letting a given sample stand for a longer or shorter time. The suspended matters have thus been more or less completely disregarded. Macdonald, in England, and Tiemann and Gärtner, in Germany, have no other methods to propose.

By straining through cloth a known amount of water, and afterwards detaching the organisms held back by the cloth upon a slide, where they could be approximately enumerated, the biologists working for the Massachusetts State Board of Health made a decided step in advance. Mr. A. L. Kean, working under my direction, has introduced a still more valuable method in the use of a sand-filter, and the subsequent quantitative examination of a thousandth part of the whole, in a ruled cell holding one cubic millimeter. Still more recently I have myself constructed a counting chamber, so arranged that a cubic centimeter, or more, of water may be examined directly, or, in case the organisms are few, the entire mass of sand and organisms left by filtration of a known amount of water (usually 100cc.) can be evenly distributed on a glass plate, then viewed with a moderately high power, and the organisms studied and enumerated with considerable precision. A full account of the various methods will appear in the forthcoming report of the State Board of Health of Massachusetts. At present I will only state that this one consists, first, in the *concentration* (if necessary) of the organisms in a large amount of water into a small amount, so that they may be readily scrutinized. This is done by filtration through a short column of fine sand in a narrow-stemmed funnel, the sand being supported upon a platform of the finest wire-gauge cloth. To secure the second point (the *enumeration*) the sand and organisms are washed down by distilled water into a shallow chamber or ruled cell one inch wide and two inches long, bordered by brass strips one-quarter inch high, firmly cemented to the slide. This counting chamber is so divided by the ruled lines that it contains 1,000 squares each $\frac{1}{5}$ inch on the side. The squares, therefore, nearly or quite fill the field of a low power objective, such for instance, as the B. B. of Zeiss. By the selection of representative squares it becomes possible, provided the organisms be evenly distributed, to estimate with considerable precision the total number of organisms upon the plate. In practice 20 squares are

usually counted and the sum obtained is multiplied by 50, thus giving the amount in 1,000 squares, *i. e.*, upon the whole plate. The sand may, after some practice, be easily neglected, and does not interfere. In the choice of the special arrangement of ruled lines, and especially in the patient construction of several finished plates by means of the dividing engine, I have been very greatly aided by my friend and former pupil, Miss C. A. Woodman.

From my results it appears that a teaspoonful of drinking-water often contains from twelve to fifty microscopical microorganisms, and may sometimes contain thousands. Indeed, they often far outnumber the bacteria, as, for instance, in the Newton reservoir, where, with 1,602 microscopical, only 6 bacterial microorganisms were found in a cubic centimeter of water. In this connection I may mention a curious result which was disclosed by an application of the method to the Newton water supply. Water was drawn from the tap in the railway station at Newton Highlands every morning, excepting on Sunday. On Mondays the numbers were observed to be very high, reaching into the thousands per cubic centimeter, while during the rest of the week they barely reached hundreds. Inquiry disclosed the fact that on week days water is pumped from the filter-basin directly into the service-pipes. On Sundays the pumps are not run, and the pipes are filled from the reservoir. The reservoir water, however, is much less pure than that drawn directly from the filter-basin; and this fact became immediately and strikingly apparent by the examination of a sample collected early on Monday morning, before the pipes had been filled from the filter-basin.

It may fairly be claimed, I think, that we now possess a simple, convenient, and effective method for the enumeration and study of the microscopical microorganisms. There is no doubt that this is a step forward in the biological analysis of water, which must henceforward include microscopical as well as bacterial examinations.

As the result of his own studies upon drinking-waters, Cohn, in the paper already referred to, laid down certain generalizations that do not seem to have attracted the attention which, if true, they should have received. For example (*l. c.*, p. 113): "We may divide the organisms in drinking-water [wells] into three categories, which correspond to different degrees of purity of the water:—

"1. Diatoms and green algæ indicate a water to which light has had access, and one poor in organic matter.

"2. Certain of the larger infusoria, especially the ciliated forms, feed on these algæ; while upon both the infusoria and the algæ feed —

"3. Entomostracans, like Cyclops and the water-flea, worms, such as Nais and rotifers, and insect larvæ."

The presence of these last scavengers-in-chief Cohn does not regard as inconsistent with the purity of the water. He considers it to be the function of the rhizopods, carnivorous infusoria, rotifer vulgaris, mites, and the water-bears, to devour solid or undissolved bits of organic matter; and of the mouthless infusoria and the bacteria to flourish upon dissolved organic matters. The latest German work upon this subject (*Untersuchung des Wassers*, Tiemann und Gärtner, 1889) does scarcely more in this direction than quote the above remarks of Cohn, and adds, "At the present time more stress is to be laid upon the quantity than upon the quality of the microscopic organisms."

In my opinion, it is in working out precisely such inter-relations and inter-dependencies of the microorganisms as are suggested by Cohn that we are now making real progress, and are likely to advance in the near future. It is self-evident that such laws, if firmly established, must become of the greatest scientific and practical value to all concerned in the use and supply of wholesome drinking water.

It is necessary, however, to go one step further. The protest of Dr. Hassall, quoted above, against the use by chemists and others of the indefinite term "organic matter" has lost none of its force by the lapse of time. On the contrary, the term thus used is less defensible than ever, and the time is gone by for students of water supplies to be satisfied if in reports of chemical analyses they find "the different kinds of organic matter, vegetable and animal, living and dead, all lumped together." Recent investigations show that such terms as "nitrates," "nitrites," and "free ammonia," have a definite meaning in important biological conditions.

Finally, it is not too much to affirm that, if it ever existed, the time is gone by when either a microscopical examination alone, or a bacterial examination alone, will suffice to base a professional or expert opinion of water upon. And furthermore, it is becoming clearer every day that an opinion of a water based upon chemical observation alone

(and, above all, upon a single analysis) is no longer a complete scientific opinion. A water analysis henceforwards must be three sided, viz., chemical, bacterial, and microscopical; and even then the conditions of the origin and of the neighborhood of the source of the water must be included as factors of equal importance. The standard of water analysis has of late appreciably risen, and reports of "water analyses," if they are to fulfil the conditions imposed by the most recent progress, must include three different examinations, as follows:—

- I. ENVIRONMENTAL, *i. e.*, a more or less complete study of the source of the water, together with observations of the surroundings, and investigation of specimens unquestionably normal, from the vicinity.
- II. CHEMICAL, *i. e.*, the usual chemical analysis, with special attention, however, to the state of the nitrogen present.
- III. BIOLOGICAL, *i. e.* (1), *Microscopical*, viz., a determination of the number, the species, and, as far as possible, the conditions of the larger microorganisms present; as well as of the masses of *débris*, etc.
 (2) *Bacterial*, viz., a determination of the number, and, as far as possible, of the species of the living bacterial organisms present.

MEETING 393.

The History and Theory of Cohesive Construction as Applied Especially to the Timbrel Vault.

BY MR. RAPHAEL GUASTAVINO.

The 393rd meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, October 24th, at 8 P. M., President Walker in the chair.

After the reading of the records of the previous meeting and the election of new members, the President introduced Mr. Raphael Guastavino, of New York, who read a paper on "The History and Theory of Cohesive Construction as applied especially to the Timbrel Vault."

Mr. GUASTAVINO first took up the history of cohesive construction, and showed by numerous examples that this construction was very ancient, and was not any particular invention, nor originated by any determined civilization, but was only the fruit of necessity. It reached the height of its splendor in the middle ages and gradually disappeared in the same proportion that modern civilization and the Renaissance approached. This decline was mainly due to the fact of the disuse of the hydraulic mortars of the Romans, Arabians, and Byzantines, and that the art of manufacturing these materials which constituted the base of their cohesive construction was lost.

The first time that cements were generally used in modern days was from 1845 to 1850. From this date commenced the renaissance of "cohesive construction."

The speaker said: The works of this character that I have constructed in Spain, as, for instance, the manufactory of Batlló, in the Corta de Sarria, where there are employed two thousand people with one thousand looms and 64,000 spindles, the other manufactories of Vidal, Muntadas & Co., and the woollen manufactory of Carreras, and the glass kiln of Cassademun with one arch of sixty-five feet span, with only ten-inch walls, and the cupola of the theatre of the town of Vilasár, of sixty-one feet span, are all permanent and durable buildings, the arches of which were built having the first two courses of plaster and the others with cement, representing 50 per cent. of the construction with plaster, as I used in my first work in this country, where we knew that the excess of plaster was dangerous, if the walls and rods were not stout enough to resist the expansion. In some cases the risk and danger caused by the irregularity of the materials was so plain that the workmen were afraid, compelling me to remain in the works to inspire confidence and success.

The progress in Spain, particularly in Barcelona, in the special construction that we now have under consideration, was due to the studies and teaching of the professors who were debating for several years how to improve their respective specialties and the way to

obtain new practical systems of construction, knowing the fact that the improvement of the material required a change and improvement in the construction, but their noble aspirations were restricted, having no facilities, and it was necessary to satisfy themselves by recommending the theories of Vicard, about the use of cements, and other applications well founded.

Nothing was done about investigating these structures to which I have referred, and no coefficients were derived. This only can be obtained when we can depend upon the materials with mathematical regularity and with powerful apparatus for determining their reliability. In countries like this, where we can find more than twenty guaranteed brands of quick-setting Portland cement of different degrees, and where clay can be used for those constructions with advantage, and where we have regularity of manufacture, and finally in a country where we have powerful apparatus, coefficients can be obtained, as we have been doing for the past five years.

From these special advantages it seems that these works have culminated in the United States, taking a natural stand in New York and Boston, with specimens that have no rivals in any part of the world for lightness and resistance.

Cohesive construction differs from "mechanical construction" or the gravity system in that the latter is founded in the resistance of any solid to the action of gravity when opposed to the solid. From these conjunctive forces, more or less opposed to one another, the result is the equilibrium of the total mass, without taking into consideration the cohesive power of the material set between the solids, while the former has for a base the property of cohesion and assimilation of several materials, which by a transformation more or less rapid resembles Nature's work in making conglomerates.

The materials employed in the construction by gravity only require the physical quality of hardness; for the "cohesive construction" the materials must not only have proper physical conditions, but it is absolutely necessary to take into consideration the chemical properties of the substances employed.

Mr. Guastavino then had two arches of about $4\frac{1}{2}$ feet span constructed before the audience in the same way they are being made in the new Public Library on Copley Square. The centers are ordinary boards cut to the proper curve, on which is laid a course of bricks of

tiles about 12" x 6" x 1", the joints being of plaster of Paris. On the completion of the first course the centers are removed. The second course is laid in Portland cement, breaking joints with the first course, as is also the third course. The whole, after it is thoroughly set, forming a solid arch.

MEETING 394.

The Kriegsspiel as Practiced in America. Its Object and Place in Military Science, and its Relations to Military and Naval Manœuvres.

BY MAJOR W. R. LIVERMORE.

The 394th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, November 14th, at 8 P.M., Mr. John C. Ropes in the chair.

After the reading of the records of the previous meeting and the election of new members, the Chairman introduced Major W. R. Livermore, U. S. A., who read a paper entitled "The Kriegsspiel as Practiced in America. Its Object and Place in Military Science, and its Relations to Military and Naval Manœuvres."

Major LIVERMORE said: Kriegsspiel in its present form is a device by means of which military operations are represented upon a map, the troops engaged being indicated by movable blocks. The movements are made, and the losses and other results of the conflict are determined, in accordance with established rules, which are designed to conform as nearly as possible to the conditions of actual warfare.

It has long been apparent that a faithful representation of military movements might form the basis of a most agreeable recreation, while affording at the same time an opportunity for students of mili-

tary science to put in practice the principles and maxims which have accumulated in great numbers in the text-books.

The Kriegsspiel invented by Herr von Reisswitz, and elaborated by his son, an officer of the Prussian artillery, has met with favor among the Germans since the early part of the present century ; and now that this indefatigable people has applied to the art of war the same exhaustive and systematic study that has proved so efficient in other branches of scientific inquiry, many of the results of its labors have become embodied in this game.

Outside of Germany for a long time the game was regarded with little favor. After the war of 1866, however, it was cultivated extensively in Austria, and the war of 1870 opened the eyes of all Europe to its importance. In the United States it has been practiced to a limited extent since 1867, and its popularity has increased with the reputation of the Germans as a military nation. It is now practiced extensively in Russia, Italy, France, Belgium, and elsewhere.

The Kriegsspiel is played upon a topographical plan, with small blocks representing the troops, which are proportioned to the scale of the map, occupying as much space upon it as the troops would occupy in the field. These blocks are moved simultaneously, under the direction of an umpire, and at rates proportioned to the mobility of the different arms which they represent.

When the position of the blocks indicates that the hostile troops are within sight and range of each other, they are supposed to open fire, if the players desire it, and in this case it becomes the umpire's duty to decide the result upon the basis of experience. The rules of the game explain to him how to estimate the loss from this fire ; for example, it may have been found that, in similar cases, the number of killed and wounded has varied from ten to twenty ; by throwing a common die he decides whether to assign a greater or a less result to the case in view. The rules of the game also explain to him under what circumstances troops have been dispersed by the result of fire, and what would be the probable result of a hand-to-hand fight. Since the time of Von Reisswitz the game has been much modified ; and the different forms which it has assumed may be classed in three groups.

The first form lays down a few arbitrary rules based upon general results, and leaves the die to decide in each case when the

troops on one side or the other are compelled to retire, without regard to the losses which they may have suffered, and only taking account of topographical and other circumstances in a most vague and unsatisfactory manner.

The second form is especially adapted to the Minor Kriegsspiel, where but a few troops are employed, and where minute records are kept of the losses of each company and fraction of a company. This produces a perfect representation of a small fight or skirmish, but involves the necessity of employing clerks or assistants, and becomes very tedious when more than two or three companies are engaged.

The third form is employed when an officer of much experience can be found to take the position of umpire; one who from long familiarity with the Minor Kriegsspiel, and from practice in leading troops in action, can form a correct judgment of the possibility or results of any movement, without the necessity of making any calculations or referring to any rules.

The American Kriegsspiel has gradually been developed in the United States service upon the basis of the second form above mentioned. But by the employment of several devices upon the plan itself, it dispenses with the necessity of keeping records, while it offers facilities of instantly determining the results of calculations as minute as those of the Minor Kriegsspiel.

A glance at the maps during the progress of the game shows to the umpire not only the formation and position of the troops, but their present condition and previous history.

Autumn manœuvres are generally recognized in the scheme of military instruction of European armies. The practice in the drill-room and on the parade-ground here find their expression and their application. They are useful in affording to officers, soldiers, and sailors an opportunity to acquire practice in their profession without the great sacrifice of life and property incidental to hostile warfare. They should therefore be made to conform as nearly to the conditions of the latter as to require a similar exercise of the faculties, and to render the forms of warfare to some extent familiar to those who have to apply them.

The most perfect representation of a hostile encounter was once afforded by a distinguished soldier who thought he could save the lives of thousands of his men by occasionally sacrificing a few hun-

dred in the way of instruction. Who would not feel more respect for this spirit than for that of more conservative leaders who have led thousands upon thousands of brave men to be mowed down like sheep because they have vainly assumed that the methods learned by experience and hard practice would suffice to meet the requirements of modern warfare, without taking into consideration the important changes in the armament?

But humanity revolts against these realistic experiments and has suggested methods that approximate as nearly to hostility as is consistent with a proper regard for human life and a measurable economy of resources; and it is by no means to be assumed that these methods are less instructive than the former. If the manœuvres are properly combined with other exercises and investigations, a system of instruction results which is even more useful than that afforded by unnecessary bloodshed, for it fixes the attention firmly upon each point in succession just as a skillful general throws all the strength of his armies upon the several fractions of his enemy and overcomes them in detail, and just as every conscientious and earnest man in other trades and professions devotes all his energies successively to mastering the difficulties of his calling.

To determine how far practice in the Art of War can be taught in time of peace, and without violating what is called in the text-books the "Peace Conditions," let us consider the form of manœuvres that differs the least from hostile encounters.

In general terms, in the autumn manœuvres in Germany a condition of hostility is assumed, the forces available are divided between the opposite sides in accordance with the problem, and the exercise proceeds as if in earnest, with slight modifications to avoid unnecessary destruction of property, until the combatants come within reach of each other's weapons. The umpires then decide the effects and consequences of the firing each in his own sphere, in accordance with recognized rules and principles, based upon the experience of past warfare which has been systematized and digested for the purpose. The defeated troops then fall back as directed by the umpires, and the operations proceed until the problem has been solved, or until the time fixed for the manœuvres has expired.

The following are some of the features in which this exercise differs from war:—

1. The firing is not conducted with ball cartridges.
2. The troops do not fall back from fear of death.
3. They do not collide.
4. The action is sometimes suspended to enable the umpires to decide the result.
5. The farmers' crops are sometimes avoided, where in war they would be trodden down.
6. The ground sometimes shelters troops from sight where they would be exposed in war.

The modifications 4, 5, 6, introduced mainly with a view to economy and like considerations, are far from detracting seriously from the value of manœuvres for military instruction.

On the field of battle the combatants are urged on in the heat of excitement to the attainment of certain ends, and are only too apt to be biased by their immediate surroundings, but in the manœuvres the modifications and pauses serve to fix the attention of officers and men to remoter influences.

It is understood that the manœuvres of the other continental nations are similar in character to those of Germany. The method of deciding the effect of fire under all conditions is identical with that employed in Kriegspiel, and constant practice in this exercise and applications of its principles, beginning with operations on a small scale on the map and in the field, affords to the umpires excellent preparation for their duties in the manœuvres. In making their decisions account is taken of all the modifying factors dependent upon the nature and circumstances of the troops delivering the fire and those subjected to it.

It is probable in European manœuvres these factors are not computed as in the Minor Kriegspiel, and in the American practice, but estimated as in the freer form of this exercise. But it should be remembered that by whatever method the Kriegspiel calculations of the effect of fire are made, they are based upon the results of the experience of war so modified as to take account of improvements in the mechanism and use of weapons, and it must not for a moment be inferred that they depend upon the results of target practice alone.

Thus, military history and statistics form the basis of Kriegspiel, as the latter forms the basis of the umpire's decisions in the manœuvres of opposing parties.

The highest order of manœuvres cannot be considered independently of Kriegsspiel, nor can the latter attain its highest usefulness unless supplemented by manœuvres; nor can either be developed without a proper study of military history and science.

MEETING 395.

The History and Theory of Cohesive Construction as Applied Especially to the Timbrel Vault.

BY MR. RAPHAEL GUASTAVINO.

The 395th meeting of the SOCIETY OF ARTS was held at the Institute on Tuesday, November 26th, at 8 P.M., Prof. G. Lanza in the chair.

After the reading of the records of the previous meeting, the chairman presented Mr. Raphael Guastavino, of New York, who continued the reading of the paper on "The History and Theory of Cohesive Construction as Applied Especially to the Timbrel Vault," which was begun at a regular meeting of the Society held October 24th.

Mr. GUASTAVINO said: We will begin by investigating the way in which this kind of arch works.

A "timbrel vault" of a single thickness of brick or tile has no more resistance than an arch or vault built by the "gravity system," because, no matter how good the mortar may be, there are only vertical joints, and the bricks or tiles are working as voussoirs, consequently this form of arch belongs to the gravity system, but if we put another course over the first breaking joints, and laid with hydraulic material, we will have the action of the cohesive force in this way, the mortar laid over the first course, or extrados, takes bond with it and also with the course laid on top. As soon as the cement sets, we will have shearing resistance represented by 17,820 lbs. per square

foot (test No. 4873). In this manner we introduce a new additional strength to the arch. But in the gravity system the force of gravity alone is the only force keeping the voussoirs in place by pressure against each other in the joints. These joints are not protected, and any reduction in the width of the joints in consequence of pressure, or weight on the arch, *compromise the setting* of the mortar. For this reason, in the gravity system the mortar serves only as a cushion, also, if cement mortar, because of bad setting, and adds no strength to the arch. In our "cohesive system" with horizontal breaking joints, with 17,820 lbs. per square foot shearing strength, the reduction in the vertical joints is protected so absolutely that, 1st, we can build arches of 20 feet span only 3" thick, using a center of 1" thick, and move it along as soon as a row of tiles is laid, which usually requires about fifty minutes; 2nd, it is common to see the workmen walking over the arch, free from centers of any kind, in some hours after it is built; and 3rd, *we can run the center under the arch again when it is completed, which is the most practical illustration that the arch has had the absolute repose necessary for its settlement.*

These three remarkable circumstances are of great value to architects, as they can be put in the *specifications*, and can be depended upon as absolute proof of the safety of the construction.

But this horizontal breaking joint is not the only great advantage of the system, there are others, the principles of which we will try to explain.

It is evident that if we were able to build an arch without joints it would be the best, having no settlement, but as the gravity system has only voussoirs of stone or brick, a certain number of joints is necessary.

Let us suppose that we have a brick arch of 6 feet span; we shall have of common brick about 26 or 27 joints, these joints being $\frac{1}{4}$ of an inch thick, represent about 7 inches of mortar, which is compelled to set with all the weight of the voussoirs resting on the centers; the centers contracting, leave the weight or pressure on the mortar, preventing a good setting, and raising the center of pressure of the arch; this happens in all the brick arches, more or less. When this arch raises only 10 per cent of the full span it is very dangerous, because the development of the curve measures very little more than its cord, and the builder or contractor, knowing this, is always afraid when

the centers are removed, and before the architect knows it, *he brings down the center of gravity still further* by hammering in little iron wedges or nails in the joints, covering them with mortar so as not to be seen. This is not good practice, for it destroys what cohesion may still be left in the joints, but has the advantage that it prepares the brick for second-hand material, freeing it from the mortar. In our arch in the same 6 feet we have only 13 joints, $\frac{1}{4}$ of an inch each, which is only $3\frac{1}{4}$ inches of mortar; consequently, as we know that the arch with no joints is the best, the one with the least is to be preferred.

There are other advantages equally important. We know that in every arch the curve of pressure changes with the position of the load; this means that every arch must be prepared for work by deflection or tension. Suppose an arch laid in bricks in such a manner as to receive a test for tension, the resistance of this tension depends upon the cohesion of the joints, or the resistance to tension of the mortar. But we said that this cohesion in the brick arches is very unsatisfactory, and is only a cushion in many cases, but when these joints have a good settlement the tension will only equal the cohesive strength of the mortar between the bricks, and with good Portland cement mortar ten days laid this strength is only from 80 to 150 pounds per square inch, when we have for our timber arch tensile strength (test No. 4875 and No. 4876) 287 pounds for 10 days, and 159 pounds per square inch for 7 days.

This shows that we have three advantages over the brick arches.

1st. The protection of the vertical joints by introducing the new strength coming from the horizontal breaking joints. These horizontal joints are in the 6' arch, $1' \times 3$ horizontal joints or $144'' \times 6 \times 3 = 2592''$: in the brick arches $27 \text{ joints} \times 4 \times 12 = 1296$ square inches, but the tiles have not only the horizontal, but the vertical, equaling 638; $638 + 2592 = 3230$ for the tile arches, against 1296 for the brick arches. As the cement is the principal element of strength in the construction, if we call it 100 pounds for 10 days' setting, we will have for the brick arches 129,600 pounds, and for the tile arches 323,000 pounds.

2nd. The less number of vertical joints, amounting to only 5 per cent of the full span, while the brick arch has 10 per cent.

3rd. The resistance to the deflection (bending moment).

The result of these advantages is the surprising strength of the timbrel arches, so that no one can at first understand how 15 or 20 feet arches, 3 inches thick, and 10 per cent rise, as we before said, can be laid, then taking away the centers at once, giving them over to the uses of the building in a few hours, when an arch of brick 6 feet span, 4 inches thick, and 10 per cent rise requires for constructing it strong and heavy centers, and repose for several days; and besides that, that 6 feet span, 4 inches thick, and 10 per cent rise is not safe construction; this span requires 8 inches of thickness as all architects and builders know.

We can consider as a safe relation between the brick and timbrel arches an arch 4 feet 6 inches span, 10 per cent rise, 4 inches thick, with cement mortar as is usual in buildings, is equivalent to 12 or 15 feet span, timbrel arch, 3 inches thick, 8 to 10 per cent rise.

All that we have said about the brick arches in comparison with the timbrel arch can be applied to the construction of concrete or conglomerate arches, especially in regard to the inconvenience of using heavy centers, and imperfect settlement of the material. In large arches the cement cannot be put over the arches quickly enough, so that every layer can settle evenly and the excessive use of the pounder kills the cement in such a way that at the moment there seems to be a small settlement; the last layer generally looks right, while inside it is all mud. That is the reason that for forty years these concrete arches have been tried without success, except in small arches, where the helpers that are generally used in this kind of work can control the full span of the arch with one single coat, having a uniform settlement, but not without using more material than necessary.

I give an instance of the use of concrete. In the foundation of the manufactory of Battillo Bros., I specified cement concrete for three feet all along the foundations as a first course, putting on top four courses of brick ($6 \times 12 \times 1\frac{1}{2}$) about the same as we are now using, this was in 1869, twenty years ago,—I gave orders to lay the concrete in layers 6" at a time; the cement was slow setting, yet I could see some signs of set. The next day when inspecting the work I found it all a mass of mud; it cost me ten days' labor, and many barrels of cement in experimenting with different brands before I ascertained the true cause; it was necessary to adopt an hydraulic

mortar composed of two parts lime, two parts sand, and three parts brick dust, in order to give very slow mortar, because cement requires repose for a certain length of time in which to set, and this putting it on in 6" courses, and hammering it down, so jarred the whole mass that its rest was disturbed and its setting qualities killed. This can be seen in the use of our tiles; two minutes after the tile is bedded in the arch the cement has begun to set, and cannot be disturbed or used again, when the same cement in the mortar bed will remain several hours without setting.

In May, 1887, I commenced a serious of experiments in the department of Tests and Experiments with the Engineer, A. V. Abbott, and I obtained the following coefficients:—

COMPRESSION TEST.

No. 4817, May 8, 5 days,	. . .	2277 lbs. per square inch.
" 4818, " 3, 5 "	. . .	1624 " " " "
" 4869, June 6, 5 "	. . .	1430 " " " "
" 4870, " 6, 5 "	. . .	2911 " " " "

An average of 2060 lbs. per square inch.

No. 7473, Oct. 21, 1889, 1 year,	. . .	3290 lbs. per square inch.
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TRANSVERSE.

No. 4871, June 6,	. . .	90 lbs. per square inch.
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TENSION.

No. 4875, June 7,	. . .	287 lbs. per square inch.
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SHEARING STRESS.

No. 4873, June 6, in Portland Cement,	124 lbs. per square inch.
" 4872, " 6, in Plaster of Paris,	34 " " " "

The formula I am using is $TC = \frac{LS}{4r}$ for concentrated load, and $TC = \frac{LS}{8r}$ for distributed load, where T = thickness of arch in middle, or area of cross section. C = Coefficient = 2060 lbs. per square inch breaking load. S = Span. r = Rise of arch.

We use the first formula to get the thickness necessary at the center of the arch with a single load and independent of the weight of the arch itself. After that we find the line of the extrados of the arch in a graphical manner, derived from the formula given by Dejar-din, for tracing the equilibrium profile of the extrados for the vaults, giving the section of the arch in the skewbacks or base of the arch on each side.

MEETING 396.

The Development of Magazine Guns for Army Use.

BY CAPT. A. H. RUSSELL, U.S.A.

The 396th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, Dec. 12th, at 8 P.M., President Walker in the chair.

After the reading of the records of the previous meeting, the President introduced Capt. A. H. Russell, of the Ordnance Department U. S. Army, who read a paper on "The Development of Magazine Guns for Army Use."

Capt. RUSSELL said: The first magazine gun used extensively in war was the Spencer. This has a tubular magazine in the butt stock. The cartridges lie end to end, being forced forward by means of a spring, and fed over the swinging breech-block directly into the firing chamber by working a lever underneath. It was used by some of the Northern troops during the Rebellion.

The Henry, afterwards known as the Winchester, was invented before, but it did not come into prominence until later, though the Henry was used to some extent by Northern troops during the Rebellion. This has a tubular magazine under the barrel. It is a bolt-gun, the breech-bolt being opened by a lever underneath.

The earlier magazine bolt-guns required some sort of a carrier to transfer the cartridge from the magazine to the firing chamber. This first system had a sliding carrier, and as the lever was worked the carrier was raised vertically.

The Spencer, Henry, and Winchester are all American inventions. The Winchester was tried in Switzerland, and then the Vetterli gun was modeled on it, as far as the magazine mechanism goes. The carrier of the Vetterli moves vertically, but it is worked by a bolt moving forward and back, instead of by a lever underneath, as in the Winchester. The action of the bolt is like a door bolt.

We now come to another American invention,—the Ward Burton gun,—where the carrier is a rocking piece or spoon, so arranged

that the cartridge, being forced on the spoon from the tubular magazine under the barrel, would be tilted up as the bolt is drawn back, so that the forward movement of the bolt would drive it into the chamber.

The new French gun (Figs. 1 and 2), and the similar gun on trial in Germany (Figs. 3 and 4) are examples of this action.

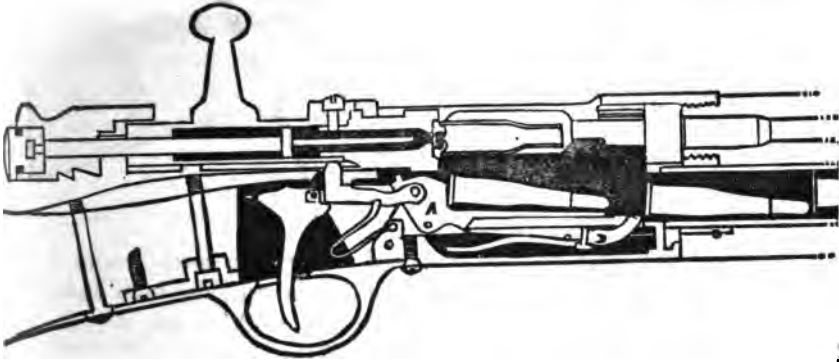


Fig. 1.

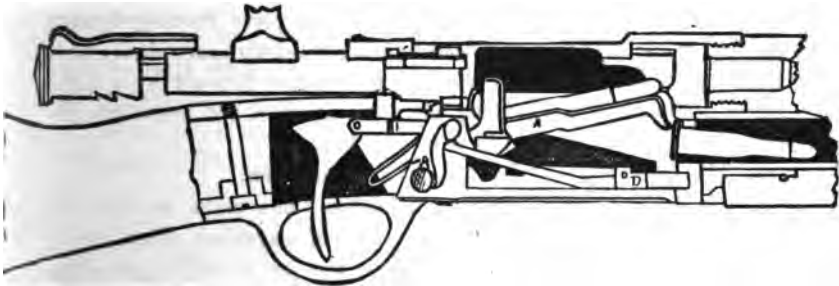


Fig. 2.



Fig. 3.

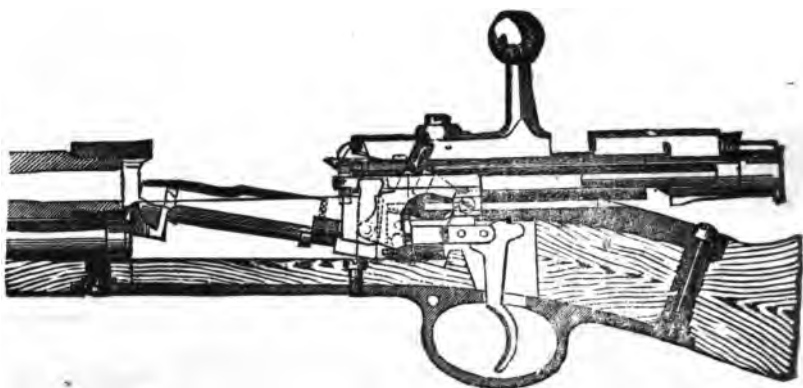


Fig. 4.

The Hotchkiss bolt-gun simplified matters very much because it dispensed entirely with the carrier. In this the magazine leads under the bolt right into the chamber from the butt stock, so that one cartridge after another is presented in front of the bolt and pushed into the chamber.

In the Evans gun there is a revolving piece running through the butt stock, with four grooves which are filled with cartridges; and, as this piece revolves, the cartridges are pushed forward by a spiral ledge, so that they work along, one after another, and come into the chamber. This is worked by a lever below.

The Hotchkiss and Evans guns are American.

Certain devices called "quick loaders" now claim attention, as they were made in order to take the place of magazines, when people thought (and some think so now) that it was just as well to get along with a single-loading gun, having the cartridges placed where they could be reached very readily; instead of carrying them in belts, or over the shoulder, or in a cartridge box, to have them in some receptacle, either permanently attached to the gun, or made to attach at will. From these cartridge holders the cartridges had to be taken by hand, the action not being automatic, as in magazine guns proper. The first detachable device of this kind was invented by Capt. Metcalfe, of our army. The cartridges are packed in the holder or case at the armory, and it is clamped to the gun when it is to be used. Fig. 5 shows a detachable quick loader, invented by General Kelton, of our

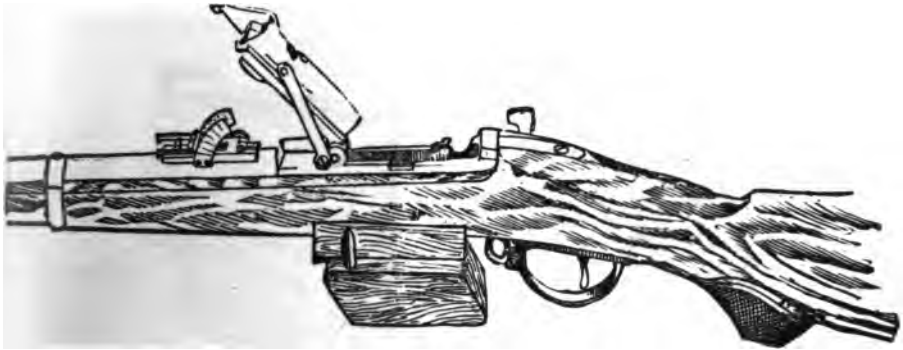


Fig. 5.

army. It is shown attached under the stock. Like the Metcalfe, it is a wooden block, perforated to hold the cartridges, but it has to be filled by the soldier.

Now we come to a very important development in magazines. These differ from the others I have described in this way, that the cartridges lie side by side, instead of being placed end to end, as in the tubular magazines.

The Lee gun is an example of this. An opening is made in the bottom of the receiver down through the stock, and the magazine is inserted from below. When one magazine is exhausted, it is taken out, and another one is put in its place. Several of these magazines are carried by the soldier, and belts are made to hold the prepared magazines. The magazines are made of steel. They have to be strong enough not to get dented or knocked out of shape, and each one has to be provided with a spring.

Figs. 6 to 8 illustrate this system. Fig. 6 gives a longitudinal section, showing the magazine in place; Fig. 7 a cross section, with the magazine removed. Fig. 8 gives a side view of the most recent form of Lee magazine.

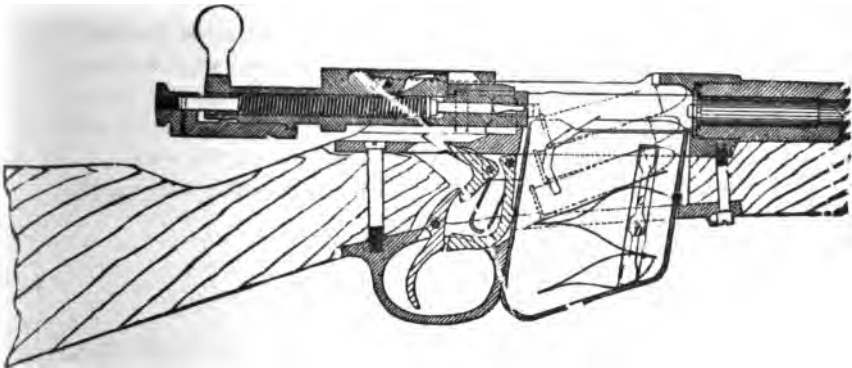


Fig. 6.



Fig. 7.



Fig. 8.

The English were not quite satisfied with a magazine that could be taken off, nor even with one that could not, so they chained one magazine to the gun, but had other detachable ones, as already described.

The Burton magazine is a detachable hopper, similar to the Franklin feed case for the Gatling gun, and made to feed cartridges by gravity down to a sliding carrier, which conveys them one by one to the receiver.

According to an article of October 16, 1887, in the *Revue du Cercle Militaire*, a perfect magazine gun should fulfill the following requirements : —

- (1) The magazine should be permanently fixed to the piece.
- (2) It should carry only as many cartridges as the soldier can fire rapidly in succession, without fatigue, and without seriously checking the forward impetus so important to a successful attack.
- (3) It should afford control of the expenditure of ammunition by allowing occasional pauses, during which the lines may be re-formed.
- (4) The form should be such that the cartridges can be inserted all at once in filling the magazine, and readily removed when necessary.
- (5) It should be so constructed that cartridges can be inserted through the magazine for single firing as well as for rapid firing, without requiring special adjustment to pass from one to the other.
- (6) The breech mechanism should work smoothly and rapidly, whether the magazine is used or not.

(7) The magazine should show at all times just how many cartridges remain in it for use.

(8) In an assault, even after the magazine has been emptied by a rapid preliminary fire, it should be possible to refill the magazine during the rush if necessary, so that on reaching close quarters with the enemy the soldier may be able to deliver a rapid and abundant fire after the bayonet charge.

(9) The arrangement of cartridges should be such that the bullets of the cartridges cannot be upset and injured in the magazine.

(10) There should be no danger of the explosion of cartridges in the magazine.

(11) It should allow the main parts to be dismounted, cleaned, and put together again, even in the field or under fire if necessary.*

(12) The gun should be strong and simple, even if rude in construction, to stand the wear and tear of drill and service.

(13) It should not require removal from the shoulder in continuous firing.

The *Revue Militaire de l'Etranger* adds :—

(14) In continuous firing, the gun should not require removal from the shoulder, nor removal of finger from the trigger.

(15) Filling the magazine should not require opening the breech, nor withdrawing the charge if the piece is loaded.

(16) It should be as easy to refill the magazine as to put a single cartridge into the simple breech loader, cartridges being carried in light boxes to serve as chargers.

The 4th, 5th, 15th, and 16th requirements indicate that the magazine should allow refilling by inserting the cartridges one at a time, when partly exhausted, or all at once when the magazine is empty.

Other authorities say the magazine should be detachable, easily replaced when empty by another full magazine held in reserve, but all agree that the perfect magazine should allow a fresh supply of cartridges to be rapidly added to the gun for instant use. The great principle sought for, first in breech-loaders, now in magazine guns, has been "to reduce to a minimum the time during which the soldier remains with gun unloaded after each shot. It is not always necessary for a man to fire rapidly, but he should be able to load rapidly, as this gives him more confidence and affords a longer time for aiming with care.

* This seems to be a very unnecessary demand.

I claim for Major W. R. Livermore, U. S. Army, and myself that we were the first to enunciate many of these very principles. Also, that we were the first to present for trial a magazine depending upon these principles, and not requiring an essential part of the working mechanism to be detachable. We had the magazine fixed, and depended on light packing cases for rapidly refilling it. Our first attempt was in the transformation of the Hotchkiss gun, as shown in Fig. 9. A slot in the butt-stock opens into the tubular magazine, and this slot can be filled by hand with loose cartridges, or by means of the prepared packages. The cartridges are then fed forward through the tube.

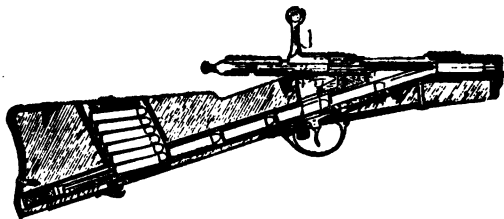


Fig. 9.

We then devised a fixed magazine which fulfilled most of the conditions just spoken of. This magazine is placed at the side of the receiver, with an opening at the top where the cartridges can be inserted. This is arranged so that one cartridge can be put in at a time, or all can be put in at once from a packing case which is placed over the mouth of the magazine, the cartridges being forced down into the magazine with the finger, and the case thrown away. This can be done whether the gun is loaded or not. Means are also provided for cutting off the magazine if desired. There is also a slot in the side of the magazine which enables us to see how many cartridges remain ready for use.

Fig. 10 is cross section of this gun through the magazine, and Fig. 11 represents the packing case used for filling this magazine and the Hotchkiss modification above described. Fig. 12 is a view of the gun and magazine. The bolt was made to work forward and back without turning, a principle followed in the more recent Mannlicher gun mentioned below.

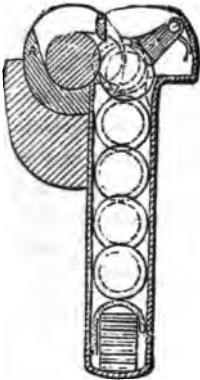


Fig. 10.

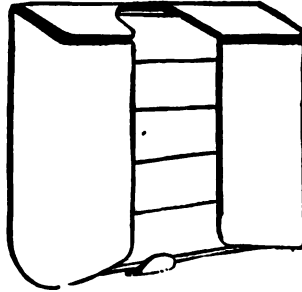


Fig. 11.



Fig. 12.

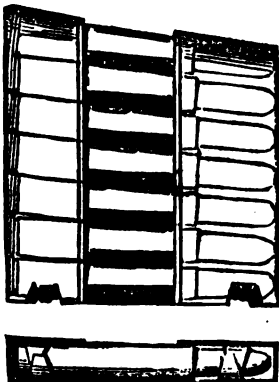


Fig. 13.

A recent Swiss gun — the Rubin — is filled from packages identical with those devised by us. Fig. 13 is an illustration of the Rubin packing case, which is also used with the Schulhoff gun described below. In the Rubin gun the breech bolt has to be drawn out before filling the magazine, which is only accessible through the receiver, being in position like that of the Lee, but fixed instead of detachable.

The Schulhoff gun is another of the recent foreign guns. The magazine is drum-shaped, and placed under the receiver. Within this drum is a revolving carrier, which causes the cartridges to run around a central spindle, and presents them one after the other at the bottom of the bolt. This magazine, can be filled with cartridges one at a time or all at once from a packing case. Fig. 14 gives a view of the Schulhoff gun; Fig. 15 a cross section through the magazine.

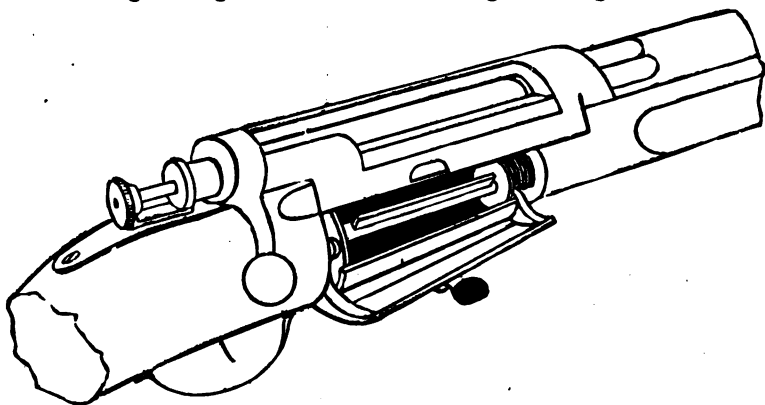


Fig. 14.

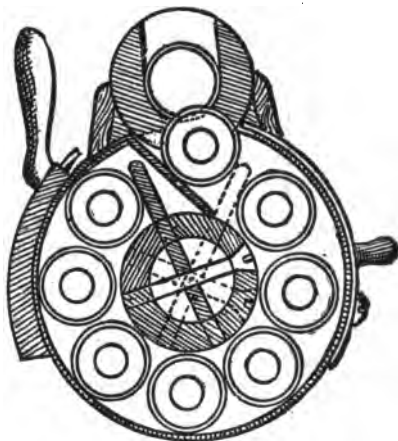


Fig. 15.

In the Austrian gun, the Mannlicher, the bolt, instead of being pushed in and turned, is operated by a forward-and-back motion simply. The magazine is fixed under the receiver, like the Rubin. A packing case filled with cartridges is inserted in the magazine and left there, the cartridges being fired from the case, and when the case is emptied it drops through a slot in the bottom of the magazine. This gun cannot be used for single firing, and the cartridges cannot be inserted one at a time. It also has the disadvantage that it is necessary to open the breech to fill the magazine, as the packing case has to be inserted through the receiver.

Fig. 16 shows the Mannlicher gun, and Fig. 17 the packing case used to fill it. Fig. 18 shows the small caliber cartridge with projecting flange used in the Mannlicher. The flanges have to be overlapped in the magazine to leave the top one free to move forward with the bolt, and a corresponding arrangement is necessary in the packing case, giving it a definite top and bottom.

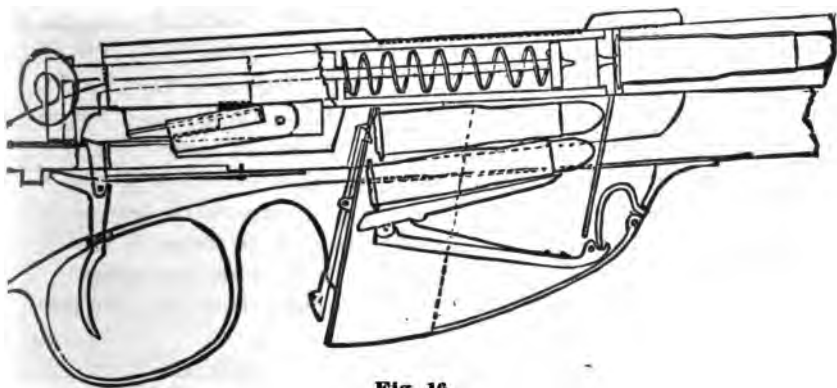


Fig. 16.

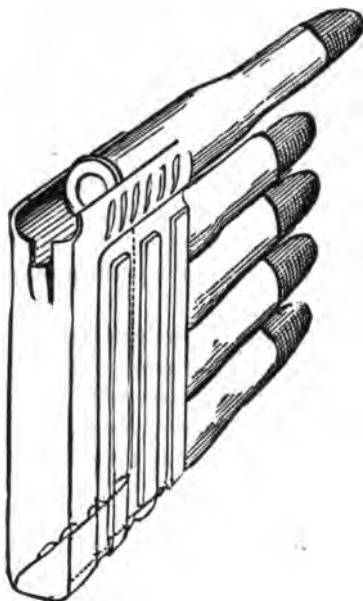


Fig. 17.

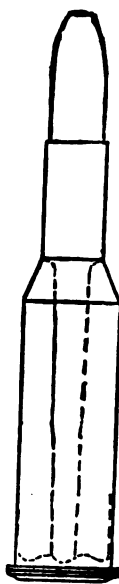


Fig. 18.



Fig. 19.



Fig. 20.

In place of the German gun, illustrated above in Figs. 3 and 4, one having a magazine similar to the Mannlicher has been adopted for the German army; the bolt being of the old pattern shown in these figures. The use of flangeless cartridges allows the insertion of the packing case either side up. A groove around the base of the new cartridge gives a hold for the extractor, as shown in Fig. 19, but this does not show the bottle shape of the German cartridge.

Fig. 20 shows the U. S. service cartridge caliber .45. The cartridges are shown in actual size.

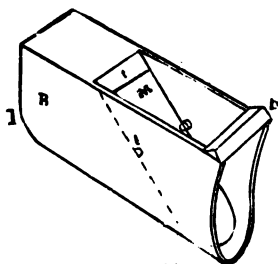


Fig. 21.

Capt. Russell also exhibited an inspecting mirror of his invention for examining the bore of breech-loading small arms. Fig. 21 gives a view of this instrument, and Fig. 22 illustrates its use with the Springfield rifle.

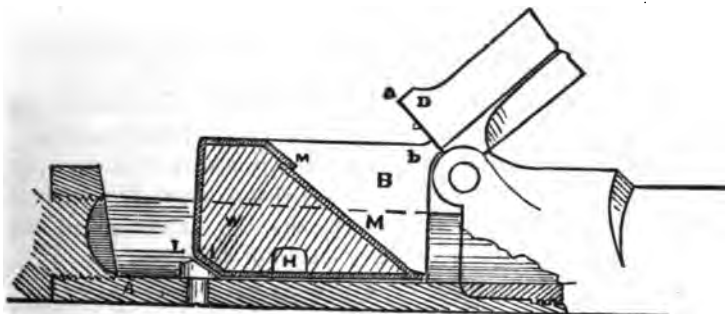


Fig. 32.

Most of the guns already spoken of were exhibited, as were also the Peabody, the Colt rifle, and several others.

Numerous drawings, representing sections, etc., of many styles of guns, arranged in the order of development, were used to illustrate the lecture. Among them were drawings of the Maxim automatic recoil rifle, and an electric gun. Illustrations were given of magazine guns, like the Spencer shot gun, and the Colt rifle, operated by means of a slide under the barrel; also of the Burgess gun, operated by means of a slide on the small of the stock. The latter has the advantage of operation with the right hand, while the left hand, grasping the barrel, steadies the piece.

At the close of the paper, Capt. Russell expressed his thanks for the courtesy shown by Hartley & Graham, of New York, William Read & Son, and J. P. Lovell Arms Co., of Boston, in offering and furnishing arms for exhibition.

MEETING 397.

The Physical Properties of Iron and Steel at Higher Temperatures.

BY MR. JAMES E. HOWARD.

The 397th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, January 9, 1890, at 8 P. M., Prof. Gaetano Lanza in the chair.

After the reading of the records of the previous meeting, the Chairman introduced Mr. James E. Howard, of Watertown Arsenal,

who read a paper on "The Physical Properties of Iron and Steel at Higher Temperatures."

Mr. HOWARD said: The results which I have the pleasure of presenting are from experiments made at the Watertown Arsenal.

First referring to the coefficients of expansion or dilatation by heat. The range of temperature employed was about 210 degrees Fahr., as shown by mercurial thermometers, the expansion of the metal being observed over a specimen length of 35 inches.

The method of measuring the expansion was as follows:—

A gauged length was laid off on the experimental bar and defined by drilled and countersunk holes. A micrometer, mounted on a carrying frame which had conical points made to enter these drilled holes in the specimen, enabled the length of the latter to be measured and compared with the length of a standard bar. When in use the standard bar was kept at a uniform temperature in a bath of ice-water.

The experimental bars were first placed in the ice-water bath and initial measurements of their lengths taken, after which they were transferred to a bath of hot oil and again measured. Generally, the specimens were returned to the cold bath and remeasured for the purpose of verifying the observations previously made. The bars remained in each bath at least two hours before measuring. The micrometer was compared with the standard before and after each reading on the experimental bar.

Tables I and II state the chemical composition and the coefficients of expansion determined with two series of steel and iron bars.

Table I.

FIRST SERIES OF BARS.

Metal.	Marks.	Chemical Composition.				Coefficient of Expansion. Per degree Fahr. per unit of length.
		C.	Mn.	Si.	Fe. by difference.	
Wrought Iron..	S. 3.	..	..	..	....	.0000067302
Steel	1-833	.09	.11	..	99.80	.0000067561
"	2-123	.20	.45	..	99.35	.0000066259
"	3-782	.31	.57	..	99.12	.0000065149
"	4-795	.47	.70	..	98.93	.0000066597
"	5-803	.51	.58	.02	98.89	.0000066302
"	6-797	.57	.93	.07	98.43	.0000063891
"	7-823	.71	.58	.08	98.63	.0000064716
"	8-750	.81	.56	.17	98.46	.0000062167
"	9-756	.89	.57	.19	98.35	.0000062335
"	10-334	.97	.80	.28	97.95	.0000061700
Cast (Gun) Iron	.....	..	..	..	.....	.0000059261
Drawn Copper.	.....	..	..	..	.....	.0000061286

Table II. SECOND SERIES OF STEEL BARS.

Marks.	Chemical Composition.						Coefficient of Expansion. Per degree Fahr. per unit of length.
	C.	Mn.	Si.	S.	P.	Cu. Fe. by difference.	
1	.17	1.13	.022	.122	.079	.040	.0000067886
2	.20	.69	.037	.130	.078	.260	.0000068567
3	.31	1.26	.080	.140	.069	....	.0000067623
4	.36	1.07	.110	.096	.080	.047	.0000067476
6	.26	1.26	.070	.112	.060	.036	.0000067103
7	.26	1.28	.070	.115	.062	.035	.0000067175
8	.28	1.23	.090	.168	.090	.178	.0000067794
9	.43	.97	.050	.080	.096	.024	.0000066124
10	.43	1.08	.037	.080	.114	.233	.0000066377
11	.53	.75	.100	.078	.067	.174	.0000064181
12	.55	1.02	.050	.078	.120	.150	.0000066122
14	.72	.70	.180	.070	.130	.230	.0000064330
15	.72	.76	.200	.066	.066	.186	.0000063090
16	.79	.86	.210	.064	.093	.066	.0000063562
17	1.07	.07	.130	.010	.078	.060	.0000061528
18	1.08	.12	.190	.011	.020	Tr.	.0000061703
19	1.12	.10	.090	.013	.018	Tr.	.0000062589
20	1.14	.10	.150	Tr.	.018	Tr.	.0000060716
21	1.17	.10	.100	Tr.	.018	....	.0000061333
22	1.31	.13	.190	.011	.096	Tr.	.0000061478

From these tables it appears that the expansion of wrought iron and mild steel is greater than that of hard steel and cast iron. The expansion of mild steel was found to be about 67 ten millionths of its length per degree Fahr. In steel of 1 per cent carbon the rate of expansion falls to 61 ten millionths, and the expansion of the cast iron was less than that of the hard steel.

In the first series of experiments variations in the rate of expansion followed approximately the carbon of the steels, and also the quantity of iron present.

In the second series there was a wider range taken by the other elements, and indications here led to the conclusion that carbon has the greater influence upon the rate of expansion. This deduction applies to annealed metal, or that which has been finished hot.

Ten bars of the first series, representing steels containing from .09 to .97 per cent carbon, were subjected to the special treatment of being heated a bright cherry red and quenched in oil, reheated and quenched in water. The first quenching was done in oil at 80 degrees Fahr.

The behavior of the bars under rising temperature seemed erratic, especially the high carbon bars which appeared to have an abnormally low rate of expansion. Returning the bars to the cold bath their contraction, although not identical, agreed fairly well with their expansion observed previous to the oil treatment.

The seemingly erratic behavior under rising temperature was now explained by the permanent changes in lengths which were found to have occurred while heating and cooling to and from 235 degrees Fahr. Generally the bars were found permanently shortened at the close of these observations, a feature very pronounced in the bars containing the highest amounts of carbon.

Following the oil treatment the same bars were again heated bright cherry-red and quenched in water at 50 to 55 degrees. The same kind of behavior observed after the oil treatment was now exhibited, but in a more marked degree. Estimating the coefficients from the expansion during rising temperature, but the values of which are vitiated by the permanent changes in length then going on, and a bar containing .97 per cent carbon had an apparent coefficient of only 23 ten millionths of its length, whereas the contraction during falling temperature indicated a coefficient of 73 ten millionths, and three other bars of the series gave results above 70 ten millionths, under falling temperature.

Heretofore the bars had displayed lower coefficients as the amount of carbon they contained increased, but now after hardening in water there resulted a decided elevation of the coefficients in the high carbon steels.

For a period of six hours the quenched-in-water bars were kept at a temperature of 300 degrees. This caused a further permanent diminution in length when cooled, most conspicuous in the high carbon steels, yet their coefficients remained highest. Finally, the bars were annealed by heating cherry-red and cooling in pine shavings, which restored the rates of expansion nearly to the primitive values.

If we may judge from the diminution in lengths, the mild steels more nearly reached a state of repose than the hard steels under the moderate temperatures which preceded final annealing. Additional experiments are needed to establish the minimum temperature at which the restoration in the rate of expansion is complete and the length of time necessary to maintain that temperature.

The moduli of elasticity were obtained with the first series of bars at atmospheric temperatures, and again at higher temperatures up to 495 degrees Fahr. The specimens were strained in a bath of hot oil. Micrometer observations were taken in a similar manner to those when determining the coefficients of expansion, that is, the conical points of the measuring instrument reached down through the surface of the oil in the bath to the drilled holes in the specimen, and enabled the strains to be measured. Elevation of temperature is found to lower the modulus of elasticity. The different grades of steel, wrought iron, and cast iron behaved alike in this respect, although differing in degree.

The reduction in the modulus of elasticity for a range of about 400 degrees, beginning with atmospheric temperature, was found from 3,595 to 8,294 lbs. per square inch per degree Fahr. for the steels. Lower values were obtained with the cast iron and intermediate values with the wrought iron.

It does not appear, however, that the reduction takes place at a uniform rate with increase of temperature; or, stated differently, the reduction is not directly proportional to the expansion of the metal by heat.

Two bars of the second series were experimented with at temperatures reaching 1,400 degrees Fahr. The heating was done in a hot-air muffle, estimating the temperatures of the tests from the expansion of the metal between reference points 10 inches apart. A specimen which contained .26 per cent carbon had an apparent modulus of elasticity of 29,000,000 lbs. per square inch at 70 degrees Fahr., which was lowered to 16,981,000 at 1,353 degrees. And another specimen containing 1.07 per cent carbon showed a reduction from 29,771,000 at 70 degrees, to 14,173,000 lbs. per square inch at 1,400 degrees Fahr.

Observations on these two bars at intermediate temperatures indicated an accelerating rate of reduction of the modulus of elasticity as the temperature increases. Overstraining at atmospheric temperature causes a temporary reduction in the modulus of elasticity. The effect of overstraining at high temperatures upon this point is not conclusively indicated by these experiments, the evidence of different tests being of a conflicting nature. This important feature will be investigated in subsequent tests.

The experimental bars under tensile test were enclosed in a hot-air muffle. The heating was done by means of gas burners arranged within the muffle and below the specimen. By varying the number of burners in use, the pressure of the gas, and changing diaphragms in the muffle, a fairly uniform temperature was maintained at any desired point. The expansion of the heated specimen was measured in the same manner as described for the coefficient of expansion determinations. The holes defining the gauged lengths of the tensile specimens were six inches apart. It is not thought that the error in measuring the expansion exceeded .0002", which corresponds to a variation in temperature of 5.4 degrees, according to the lowest coefficient of expansion used. It was assumed that the rate of expansion continued uniform, and the coefficients developed at moderate temperatures were used in estimating the higher temperatures of the tests. The reports containing the full details of the tests state the observed expansions.

The elastic limit appears to diminish with increase of temperature. The limit here referred to is that at which the rate of elongation shows a rapid increase under equal increments of load. With some metals at certain temperatures the elastic limits thus defined correspond closely with the limits at which permanent sets are discovered. In other cases the elastic limit is vague and uncertain.

According to the definition adopted, it is probable that the elastic limits as recorded are not too low, and the exclusion of permanent sets would in most cases give lower values. Steel of .09 per cent carbon, which had an elastic limit of 33,000 lbs. per square inch, at 70 degrees had an elastic limit of 16,000 lbs. per square inch at 934 degrees temperature.

The tensile strength does not appear to follow the same law which governs the elastic limit. Its value diminishes for a time, then increases, and afterward diminishes. Beginning with zero temperature, the tensile strength diminishes with increase of temperature, until a minimum is reached between 200 and 300 degrees. From this temperature of first minimum strength the metal displays increased tenacity as the temperature rises until a maximum is reached at 400 to 650 degrees Fahr. From the temperature of maximum strength the tenacity diminishes until the highest temperatures are reached covered by these experiments. The mild steels appear to

reach the place of first minimum strength somewhat earlier than the hard steels. The hard steels from this first minimum increase in strength rapidly until the highest strength is attained, after which a rapid decline follows. The mild steels retain a high strength over a wider range of temperature, and do not lose in strength so rapidly as the harder metal. The greatest loss observed in passing from 70 degrees to the place of first minimum strength was 6.5 per cent at 295 degrees, which was shown by a bar containing .89 per cent carbon. The greatest gain in per cent over the strength at 70 degrees was 25.8 per cent, shown by steel of .09 per cent carbon, although in pounds per square inch it was exceeded by steel of .57 per cent carbon where the gain was 15,120 lbs. per square inch, or 12.8 per cent. The total difference in the strength of steel containing .57 per cent carbon between 214 and 587 degrees maximum and minimum places respectively was 21,200 lbs. per square inch. As higher temperatures are reached the several grades of steel approach each other in strength. Thus steels which differ in tensile strength over 100,000 lbs. per square inch at atmospheric temperature differ at the temperature of 1,600 degrees less than 10,000 lbs. per square inch. Their relative positions are retained throughout, that is, steels which are strongest cold are also strongest hot, at least up to the highest temperatures reached by these experiments.

Referring to the relative influence of higher temperatures upon the elastic limit and tensile strength, steel of .09 per cent carbon at the temperature of 460 degrees reached the maximum observed tensile strength for this grade of metal, and displayed a strength of 125.8 per cent that at 70 degrees, but at this time the elastic limit was 78.2 per cent that of the cold bar, and at 847 degrees the tensile strength was 8.4 per cent above the cold metal, while the elastic limit was only 51.5 per cent that of the cold bar. The other grades of steel behaved in a similar manner with less pronounced differences in the harder metal. One grade of wrought iron, designated by the letter B, resembled the mild steel in its behavior. Another wrought iron, called iron A, furnished an exception to the rule, that the elastic limit steadily diminishes with increase of temperature. At 689 degrees this iron had an apparent elastic limit 102.2 per cent of that found at 70 degrees. Iron A had been strained with 42,320 lbs. per square inch seven years before these hot tests were made, and this particular

iron was selected because it had been found excessively red-short at a welding temperature. The metal showed high strength, and not until reaching 1,568 degrees temperature did its hot-short crumbling nature appear. The cast iron gradually increased in strength up to 900 degrees, above which temperature the strength slowly diminished. At 1,600 to 1,700 degrees the surfaces of the specimens after rupture were broken by numerous fine cracks. It is remarkable that the cast iron at these high temperatures had about the same strength as the steels which were so much stronger cold.

Total elongation is generally greatest at ordinary temperatures. Although the metal is capable of being worked under the hammer at high temperatures, it does not then appear to have sufficient strength within itself to develop large elongation. Local contraction at the place of rupture is distributed over so large a part of the specimen at the highest temperatures that elongation independent of local contraction is not at all times clearly shown. Furthermore, as the stress per square inch on the contracted section increases as the metal draws down, it is difficult to distinguish when general elongation ceases and when the stretch is confined to the section about to rupture, unless the specimen is accessible for inspection.

The elongation of the metal under stresses below the tensile strength presents interesting features. Thus, certain bars show a yielding point at or slightly above the elastic limit, at which time stretching will continue without increase of stress, or even under reduced loads. At atmospheric temperature this yielding rarely occurs but once, and is followed by a gradual elongation having an accelerating tendency as higher loads are reached. There may follow a period of abnormal rigidity immediately after this yielding point, but of short duration. Under moderate temperatures — 200 to 400 degrees — several such yielding points have been observed, or alternate periods of relaxation and rigidity under increasing stresses.

This behavior gives a zig-zag appearance to the curve representing the tensile test.

Observations on the contractile force developed during cooling showed the same kind of behavior took place under falling temperature. It will be observed that these phenomena take place at a time when the metal is gaining in strength under rising temperature. Further, this peculiarity is noticed: that greater rigidity exists under

certain stresses at intermediate temperatures than at either higher or lower temperatures. An illustration of this kind is furnished by a bar of .31 per cent carbon tested at 569 degrees, which displayed less elongation under stresses above 50,000 lbs. per square inch, than other bars of the same grade of metal tested at higher or lower temperatures.

The stress on the ruptured section resembles somewhat but not closely the curve of tensile strength. The speed of testing affects this value more or less, and failure in detail may render it difficult to distinguish when local contraction ceases and rupture begins. With hard and brittle metal the stress on the ruptured section does not differ largely from the tensile strength: the converse is true of ductile metal. Steel of .09 per cent carbon tested at 492 degrees reached 118,100 lbs. per square inch stress on the contracted section at the time of rupture. The tensile strength referred to the primitive area was 64,560 lbs. per square inch. The contraction of area at the place of rupture also varies with the temperature of the metal. It appears that contraction of mild and medium hard steel is somewhat less at 400 to 600 degrees than at atmospheric temperature, and within this range of temperature there is a tendency to fracture in an oblique direction across the bar. This characteristic is significant in so far as it harmonizes with the brittleness observed in bending tests at these temperatures. The hard steels showed substantially the same contraction up to 500 degrees. Above 500 or 600 degrees the contraction increased with the temperature, with the exception of the hardest grades, which showed a stage of diminished contraction at 1,100 to 1,200 degrees, until at the highest temperatures some of the bars were drawn down almost to points. A specimen of .37 per cent carbon, fractured at 1,572 degrees, contracted 98.9 per cent. Occasionally there are indications specially noticeable when large contraction occurs that rupture in some specimens begins at the center of the bar. A test was discontinued after reaching 94.4 per cent contraction of area, the temperature at the time was 1,451 degrees. By filing away a portion of the outside metal after cooling, a cavity at the center of the bar was disclosed. Center-punch marks on the surface of the specimen near the place of rupture have elongated upwards of 300 per cent.

The rate of speed of testing may, within limits, modify the results with ductile metal at atmospheric temperature, and has a decided

influence upon the apparent tenacity at high temperatures. The ordinary rate of speed in making these tests was from five to ten minutes each, according to the temperature and the amount of ductility displayed. A series of tests was made with steel containing .81 per cent carbon at ordinary rates of speed, and also rapid tests. The time required to reach the maximum stress in the latter class was from two to eight seconds of time. This metal which, at ordinary temperature, has little ductility displayed about the same strength, whether rapidly or slowly ruptured, from the temperature of the testing room up to about 600 degrees. Above this temperature the apparent strength of the rapidly-fractured specimens largely exceeded the others. At 1,410 degrees the slowly-fractured bar showed 33,240 lbs. per square inch tensile strength. At the same temperature a bar tested in two seconds showed 63,000 lbs. per square inch tensile strength, as nearly as could be weighed. This illustration is an extreme one of its kind. On the other hand, prolonged stress appears capable of rupturing the metal under loads below those which were required at the adopted speeds of these tests, but the differences are not so marked as those due to rapid testing.

Such considerations naturally lead to the inquiry: What is the maximum tensile stress a metal can indefinitely sustain at different temperatures, and at what temperature does the value of such stress become reduced to zero.

A number of bars were strained hot and subsequently ruptured cold. The effect of such treatment appears to depend upon the magnitude of the straining force and the temperature in the first instance. There is a zone of temperature in which the effect of hot straining elevates the elastic limit above the applied stress, and above the primitive value, and if the straining force approaches the tensile strength, there is also a material elevation of that value when ruptured cold. These effects have been observed within the limits of 335 and 740 degrees. Bars of .57 per cent and .97 per cent carbon, respectively, overstrained within the zone of 400 to 1,000 degrees, displayed less contraction, including that which occurred during the hot test and when finally ruptured cold, than the original cold tests displayed, which behavior is in accord with the brittleness observed in some metals under bending tests after similar treatment. After exposure to higher temperatures, there occurs a gradual loss in both elastic

limit and tensile strength, and generally a noticeable increase in the contraction of area. But simply heating without straining was found to anneal and lower the strength of bars of .97 per cent carbon exposed to temperatures of 1,529 and 1,684 degrees respectively, the contraction of area, however, remaining unchanged.

The data thus far developed seem insufficient to explain the relative influence on the final strength of the metal due to exposure to high temperatures, the duration of such exposure, and the tensile stress then applied.

It does not seem inconsistent with observed facts to believe that each of these features may arrive at a stage of relative greatest importance at different places along the thermometric scale.

The color of the bars after cooling was not sensibly changed by temperatures below 200 degrees. After 300 degrees the metal was light straw colored; after 400 degrees, deep straw; from 500 to 600 degrees, purple, bronze colored, or blue; after 700 degrees, dark blue and blue-black. After 800 degrees the final color affords less satisfactory means of approximately judging of the temperature, the color remaining a blue-black and darker, until a thick magnetic oxide is formed. A smooth glazed surface was found on specimens heated to 1,000 to 1,200 degrees, which offered considerable resistance to the effect of acids, and against corrosion in a damp atmosphere. The oxide tints found at lower temperatures were immediately removed by the action of acids. At about 1,100 degrees the surface oxide reaches a tangible thickness, a heavy scale of .001 of an inch to .002 of an inch forming as higher temperatures are reached. The red oxide appears at about 1,500 degrees Fahr. When the oxide has a tangible thickness, it is more or less loosened from the surface of a ductile metal ruptured cold. Some specimens ruptured after exposure to the lower temperatures of 600 to 700 degrees have had the surface coloring slightly broken, but such is not generally the case. The fractures of specimens with straw-colored cylindrical surfaces were not colored. Those with blue surfaces showed fractured ends deep straw and brown. The fractures of dark blue and blue-black specimens agreed with the cylindrical surfaces. The specimens were allowed to cool immediately after rupture, hence the surfaces of the fractured ends were exposed to the atmosphere only a brief period of time, while at the maximum temperature.

Specific gravity determinations, although the results lack uniformity, show differences thought to be sufficiently pronounced to indicate that in general the density of the metal is materially diminished in the vicinity of the place of rupture of tensile specimens, and that this diminution takes place in the different grades of steel, in bars ruptured under different conditions of temperature, stress, and contraction of area.

The specific gravity of the truncated ogival ends of fractured tensile specimens has been found .2 per cent lighter than samples from the original hot-rolled bars. Strain caused by the application of a stress inferior to the elastic limit appears to take place at once. No difference in the deflection of a transversely loaded shaft was detected at the highest speed experimented with when the stresses changed from tension to compression in one forty-fifth of a second, the shaft being run at atmospheric temperature, and, when under the highest load, with a maximum fiber stress of 50,000 lbs. per square inch. Common experience has shown that the full effect of a load superior to the elastic limit is not immediately felt in the elongation of a ductile metal, which appears to be true also at higher temperatures. It is difficult to make a direct comparison of the rate of flow at different temperatures, as the elastic limit and tensile strength are changing in the meantime. A number of examples point to the conclusion that a more sluggish slower rate of flow may take place at high than at low temperatures. A specimen of steel of .97 per cent carbon was observed for a period of three hours, during which the elongation continued at nearly a uniform rate of speed, stretching about .0008 of its length each five minutes, under a stress of 20,000 lbs. per square inch. The initial and final temperatures of the test were 1,170 and 1,189 degrees respectively. Another example furnished by the same grade of metal, in which the observations were limited to one hour, showed the mean rate of flow to be .0015 per unit of length per five minutes, with a slightly accelerating tendency. The stress was 5,000 lbs. per square inch, and the initial and final temperatures 1,505 and 1,494 degrees respectively.

Heretofore we have been considering the effect of higher temperatures upon the strength of the metal exposed to simple tensile stresses.

Experiments were made with riveted joints, in steel boiler plates,

at temperatures from 70 to 700 degrees, over which range the results of the tensile tests of the plain bars were corroborated. Riveted joints at 200 degrees showed less strength than when cold; at 250 degrees and higher temperatures the strength exceeded the cold tests, and when overstrained, approaching the limit of rupture, at 400 to 500 degrees there was found when completing the test cold an increase of strength over the duplicate cold test made in the ordinary manner. A single riveted butt joint tested at 500 degrees ruptured with 81,050 lbs. per square inch on the net section of plate, whereas the corresponding joint tested cold failed in the same manner with 65,000 lbs. per square inch. Another joint at 500 degrees reached 119,980 lbs. per square inch compression on the bearing surface of the rivets. Still another joint, which was strained at 500 degrees, then cooled to 150 degrees and ruptured, sustained 137,110 lbs. per square inch compression on the bearing surface of the rivets.

As none of these joints failed by direct crushing of the metal at the bearing surfaces, without defining the crushing limits under these conditions of test, we are enabled to say the metal is capable of sustaining very high compressive stresses in this zone of temperature.

Rivets which sheared cold at 40,000 to 41,000 lbs. per square inch at 300 degrees sheared at 46,000 lbs. per square inch; and at 600 degrees, the highest temperature at which joints were ruptured failing in this manner, the shearing strength was 42,130 lbs. per square inch.

The internal strains in some oil-tempered and annealed steel cylinders have been investigated. The cylinders were numbered 7, 8, and 21.

The salient features of the investigation were that cylinder No. 7, which was oil-tempered, annealed, and then retempered, was found to have the entire surface metal, exterior bore, and ends in an initial state of compression, and the interior of the mass in a state of tension. The maximum stresses found were 47,161 lbs. per square inch compression, and 938 lbs. per square inch tension. The latter stress not representing, however, the maximum amount which was in the cylinder when entire, the inaccessibility of the tensile metal at the time preventing that value being ascertained. The strains in cylinders Nos. 8 and 21 were of small magnitude, showing the final process of annealing to have been very efficient. The middle section of cylinder

No. 8 was cut into two slices and each re-treated at Watertown Arsenal: the earlier treatment was done at the steel works. Slice No. 1 was heated cherry-red and quenched from the bore with oil at 65 degrees Fahr. Slice No. 2 was heated bright-red and cooled from the bore with water at 80 degrees. The maximum stresses in slice No. 1, computed from the strains which were released when the slice was cut into detached concentric rings, were 18,984 lbs. per square inch tension, and 84,669 lbs. per square inch compression, the compressive strains being next the bore. The maximum stresses in slice No. 2 were 50,814 lbs. per square inch tension, and 59,060 lbs. per square inch compression,—a total range of 109,874 lbs. per square inch in the same piece of metal. The compressive stress exceeded the primitive elastic limit of the metal. Even this is not all, for the observed stresses were the means for their respective rings, the rings which were cut apart radially showing additional strains not released until then. The inside ring of slice No. 1 was turned down in the lathe, reducing its exterior diameter in successive stages each, until its thickness had been reduced from .25" to .05" thick; in the meantime the bore continued to expand at each operation until the stress corresponding to the strain released was 50,720 lbs. per square inch, against 84,669 lbs. per square inch displayed by the entire ring. The ring was then turned down to .025" thickness and cut apart radially, whereupon the ends opened .147," thus showing that a difference of intensity of stresses remained in this thin ring. Retrogression of intensity of strains occurs very rapidly when departing from the quenched surfaces. Observations were made on the persistence of internal strains under higher temperatures. Detached rings from cylinder No. 7 were cut apart at one side, the ends wedged apart, and the rings then exposed to the annealing effect of different temperatures. The wedge was driven until the elastic limit was exceeded, as shown by the permanent set in the chord measurement across the cut. In this condition the ring was under the maximum internal strains which it was capable of receiving at atmospheric temperature. The additional permanent sets observed on the chord measurement indicated the release of internal strains after exposure to higher temperature. Strains were released at 428 degrees, and increased sets found as higher temperatures were employed. The highest temperature reached was about 1,450 degrees. This temperature did not entirely eliminate

the internal strains, the restoration in chord measurement which followed the removal of the wedge after this temperature showed the metal had an appreciable elastic limit at that temperature, although a low one. This same ring was next heated cherry-red and quenched in oil. Now, subjecting it to the temperature 410 degrees, wedged apart substantially the same amount as before, and the permanent set found was over six times the magnitude of the set after heating to nearly the same temperature in the first instance. This remarkable difference in the persistence of internal strains displayed by the ring before and after the last retempering demands further investigation in order to ascertain the influence of intervening periods of time, of different initial states of hardness, and different methods of tempering and hardening.

Specific gravity determinations with sectors from cylinder No. 7 (the pieces were small, weighing in air about 33 grammes each) showed, after heating cherry-red and quenching in oil, a slight increase in density, and when quenched in water from the same temperature a decided loss in density. Again heating cherry-red, and reversing the pieces in the quenching fluids, the same differences were displayed as before, that is, quenching in oil caused an increase in density, quenching in water a decrease in density. Heating nearly white hot and quenching in oil caused a decrease in density, as the water had done at lower temperature. As similar treatment is found to cause in different specimens both internal strains and changes in density, these two features may be regarded as correlated functions.

From what has just been said we see that internal strains are released by elevation of temperature, and the extent to which they are released depends upon the temperature reached. Earlier remarks stated that the elastic limit diminishes with increase of temperature, therefore we infer that strains in excess of the elastic limit at the annealing temperature are released by that temperature, and complete elimination of internal strains would therefore require a temperature at which there was practically no elastic limit.

Phenomena attending the over-straining and alternate straining of iron and steel are under investigation. It appears that certain steel bars which originally possess an equality of elastic limits under tensile and compressive stresses, when loaded beyond the elastic limit in either direction, lose in the elastic limit in the opposite direction.

The loss has been found very serious, amounting in some cases to almost complete elimination of the elastic limit in the opposite direction to the over-straining load. Thus, a metal having elastic limits under tension and compression each 50,000 lbs. per square inch would have a total range of stress of 100,000 lbs. per square inch before overloading. Exceeding the tensile elastic limit, say, 1,000 lbs. per square inch, and there results a loss in the compression elastic limit, so that the total range of stress within the limits of perfect elasticity is now little if any above 51,000 lbs. per square inch. Bars over-strained in this manner have been annealed at different temperatures, from 1,180 down to 278 degrees.

The equality of elastic limits was measurably restored even by the lowest annealing temperature. Under the higher temperatures the restoration was nearly or quite complete.

MEETING 398.

Combination Voltmeter and Ammeter for Electrical Measurements.

BY MR. ANTHONY C. WHITE.

The 398th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, January 23d, at 8 P. M., Mr. G. W. Blodgett in the chair.

After the reading of the records of the previous meeting, the chairman introduced Mr. Anthony C. White, of the Bell Telephone Co., who read a paper on a "Combination Voltmeter and Ammeter for Electrical Measurements."

MR. WHITE said: The phenomenal growth of telegraphy, telephony, and electric lighting during the past few years has rendered more and more imperative the demand for accurate and commercial apparatus for measuring the various quantities involved in each of these branches of electrical engineering.

At the beginning of the present century the galvanic cell was discovered. This invention was of but very little commercial importance until the discovery of the Morse telegraph in 1837. The discovery of the carbon transmitter of telephony still further increased its value, and today there is no branch of electrical engineering of more importance than that of the galvanic or voltaic battery; yet, strange to say, there has been no commercial instrument in the market for measuring the electro-motive force and internal resistance of batteries up to the present time. The result has been that there is a vast amount of superstition afloat in regard to batteries, and, outside of a few electrical laboratories, absolutely nothing is known in regard to them.

In the fall of 1887 I began a series of tests upon various batteries, with laboratory apparatus, which led to the invention of the apparatus under discussion this evening. The electrical arrangement for determining the electro-motive force of batteries was the well-known Lacoine's method, which is as follows:—

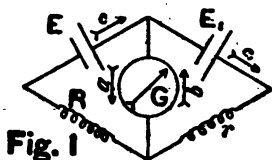


Fig. 1

In Fig. 1, E is a standard battery whose electro-motive force is already known. E_1 is the battery whose electro-motive force we wish to find. Let these letters also represent the electro-motive forces of these batteries, respectively. R represents a fixed resistance; r , a resistance which we can vary at will. G is a galvanometer. The battery E tends to send a current through the galvanometer in the direction indicated by the arrow A , tending to cause a deflection of the galvanometer needle, say to the right. The battery E_1 tends to send a current in the opposite direction, indicated by the arrow B , tending to cause a deflection of the galvanometer needle to the left. When both batteries are acting upon the galvanometer, its needle will be deflected to the right or to the left, according to which of these tendencies is the stronger. It is evident that the current that the compared battery E tends to send through the galvanometer can

be varied at will by means of the adjustable resistance r . Let us make r such that these two tendencies shall be equal. Then there will be no current through the galvanometer, and its needle will remain undeflected. In this case C , the current delivered by the standard battery, must be equal to C_1 , the current delivered by the compared battery. Furthermore, the points C and D being at the same potential, since there is no current through the galvanometer, may be connected by a wire of 0 resistance. But in this case, from Ohm's law,

$$C = \frac{E}{R} \quad C_1 = \frac{E_1}{r}$$

And since $C = C_1$

$$\frac{E}{R} = \frac{E_1}{r} \therefore E_1 = \frac{r}{R} E$$

Or, since E and R are both constants depending upon the electro-motive force of the battery used as a standard and the number of ohms chosen for the fixed resistance, we may write,

$$E_1 = ar$$

where a is some constant.

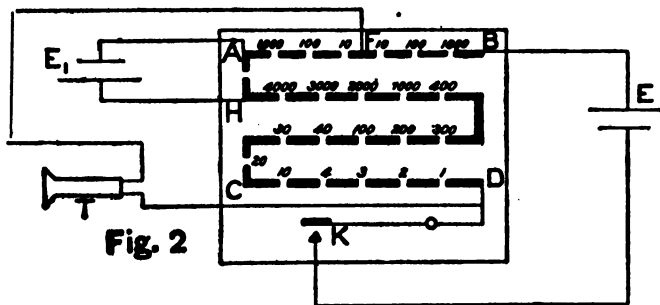


Fig. 2

Fig. 2 represents the apparatus as originally set up for measuring the electro-motive forces of batteries. A, B, C, D represents an ordinary Wheatstone's bridge. The standard battery, together with a key, is placed in circuit between B and D . The compared battery is connected so as to bridge around the infinity point at AH . One terminal of a telephone receiver is connected to D , the other terminal being left open. 1,000 ohms is thrown in at B for the fixed resist-

ances, all the other plugs between A and B being inserted. Resistance is then introduced in the variable side of the bridge, so that upon closing the key K no click is heard in the receiver when the telephone circuit is closed between D and F . The theoretical arrangement is shown in Fig. 3.

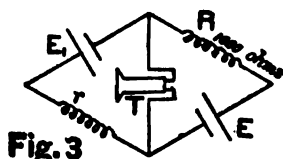


Fig. 3

This is obviously a similar arrangement to that described before, for R , the fixed resistance, controls the current delivered by the standard battery, and the variable resistance r controls the current given by the compared battery.

The apparatus that we then used for determining resistances of batteries was constructed upon the well-known Mance's method, but since it has no special bearing upon the apparatus which I shall describe tonight for this purpose, we will give it no further consideration.

Let us now discuss more in detail Lacoine's method of determining electro-motive force. From Figs. 4, 5, 6, and 7 it will be seen that there are four ways in which the galvanometer resistances and batteries can be grouped.

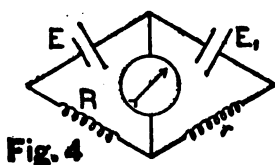


Fig. 4

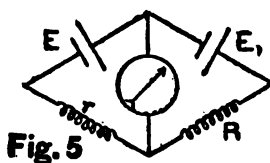


Fig. 5

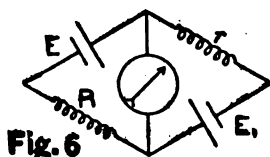


Fig. 6

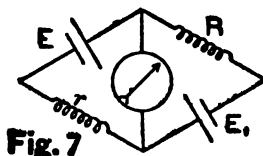


Fig. 7

In Fig. 4 the effect of the standard battery upon the galvanometer is determined by the fixed resistance, and that of the compared battery by the variable resistance, the galvanometer being connected between the medial point of the two batteries and the juncture of the two resistances. As we have before proven, the current delivered by each battery is the same when there is no current flowing through the galvanometer, and we can write:—

$$\frac{E}{R} = \frac{E_1}{r}$$

Therefore, $E_1 = \frac{E}{R} r = ar$

Fig. 5 represents the case where the fixed resistance is placed in the compared battery circuit, and the variable resistance in the standard battery circuit, the galvanometer being connected as before. When there is no current through the galvanometer we can write as above, $\frac{E}{r} = \frac{E_1}{R}$

Therefore, $E_1 = ER \frac{1}{r} = b \frac{1}{r}$ where b is some constant. From this formula we see that E_1 , the electro-motive force we are measuring, will vary inversely to the variable resistance.

To illustrate the radical difference between these two combinations, let us take for our standard battery the Daniell's cell of 1.1 volts electro-motive force, and for our fixed resistance, R , 1,000 ohms. Suppose, now, the galvanometer remains at 0 when there are 200 ohms in the variable resistance, r . Then, if our electrical connections are as represented in Fig. 4, we have for the value of E_1 the unknown electro-motive force,

$$E_1 = \frac{E}{R} r$$

$$E_1 = \frac{1.10}{1000} \times 200 = .22 \text{ volts.}$$

On the other hand, if the arrangement is such as represented in Fig. 5, the unknown electro-motive force would be, under the same conditions,

$$E_1 = ER \frac{1}{r} = 1.10 \times 1000 \frac{1}{200} = 5.5 \text{ volts.}$$

Referring to Figs. 6 and 7 it will be seen that the electrical connections in Fig. 6 are similar to those in Fig. 4, the functions of R and r being the same in both cases, and the formula representing the value of E_1 is the same as in Fig. 4.

$$E_1 = \frac{E}{R} r$$

Also, the resistances in Fig. 7 fill the same office as in Fig. 5, and we have for the value of E_1 , as in Fig. 5,

$$E_1 = ER \frac{1}{r}$$

Let us now discuss these two different applications of Lacoine's method of measuring electro-motive force, to determine their relative defects and advantages. Let us assume that we are limited to an ordinary Wheatstone's bridge, with coils ranging from 5,000 ohms to 1 ohm, the sum total being 10,000 ohms. For very accurate work I have considered it advisable to use as high a value for the fixed resistance as 10,000 ohms, and we will also assume that our standard is a Daniell's cell of 1.1 volts, and that we are measuring a storage battery of 2.2 volts. Then, if we have the arrangement shown in Fig. 4,

$$E_1 = \frac{E}{R} r$$

Or, $2.2 = \frac{1.10}{10,000} r$, whence $r = 20,000$ ohms.

But our Wheatstone's bridge only gives us 10,000 ohms, and we should be unable to measure so high an electro-motive force with the coils at our disposal.

With connections given as in Fig. 5, we should have with the same data: —

$$E_1 = ER \frac{1}{r}$$

Or, $2.2 = 1.10 \times 10,000 \times \frac{1}{r}$, whence $r = 5,000$ ohms.

With this arrangement, then, it is comparatively easy to measure high electro-motive forces with the ordinary Wheatstone's bridge where the customary arrangement would fail.

On the other hand, suppose the electro-motive force to be measured was .22 volts instead of 2.2 volts, then we have in the first case:

$$.22 = \frac{1.10}{10,000} r \quad \text{From which } r = 2,000$$

Consequently we are within the range of the Wheatstone's bridge. With connections shown in Fig. 5 we have

$$.22 = 1.10 \times 10,000 \times \frac{1}{r}. \quad \text{From which } r = 50,000 \text{ ohms,}$$

and we are beyond the capacity of the bridge. Consequently, it is comparatively easy to measure low electro-motive forces with the ordinary arrangement, where the special case would be outside the range of the Wheatstone's bridge. I have employed a 4-point switch for changing from one method to the other, and have found it entirely satisfactory.

Neither of these combinations are direct-reading, however. In the first we are obliged to multiply the variable resistance by a constant to obtain the required E, M, P . In the second we have to divide a constant by the variable resistance. Is it possible to make a direct-reading voltmeter out of either or both of these methods? Let us take the first arrangement, where

$$E_1 = \frac{E}{R} r = ar$$

If we make R of such a value that $\frac{E}{R}$ shall be unity, or some decimal of unity, so that a becomes 1, .1, .01, .001, etc., then it is evident that all that will be necessary to obtain the value of E_1 will be to change the decimal point of r . For instance, suppose our standard battery has an electro-motive force of 1.43 volts, and we make the value of R 1,439 ohms. Let us compute the values of the variable coils that will make the voltmeter direct-reading. For one volt we have:

$$E_1 = \frac{E}{R} r$$

$$1 = \frac{1.43}{1,430} r \therefore r = 1,000 \text{ ohms.}$$

And since E_1 varies directly as r , we can construct our coils thus :

1.00	volt	corresponds to	1,000	ohms	in the	variable	resistance.
.50	"	"	500	"	"	"	"
.20	"	"	200	"	"	"	"
.20	"	"	200	"	"	"	"
.10	"	"	100	"	"	"	"
1.05	"	"	50	"	"	"	"
.02	"	"	20	"	"	"	"
.02	"	"	20	"	"	"	"
.01	"	"	10	"	"	"	"

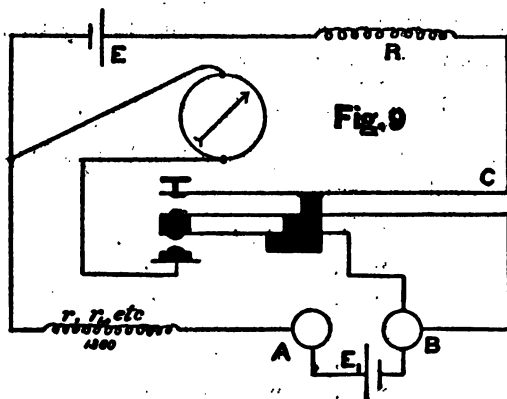
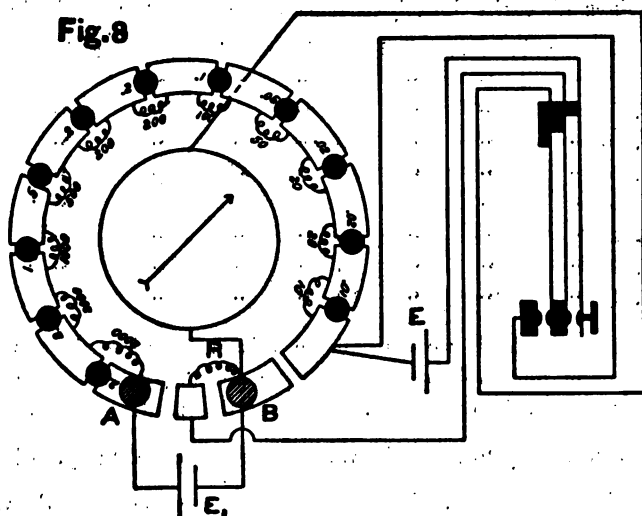
Consequently, if we construct a voltmeter with variable resistance coils of these values, we shall have a direct-reading instrument reading from 0.01 to 1.00 volt. To make this method direct-reading it is not necessary to make the value $\frac{E}{R}$ some ratio of unity, although this is the simpler way. For instance, suppose we compute the value of r which would make E_1 unity, the standard battery and fixed resistance having been chosen beforehand. Let us assume our fixed resistance R is 1,375 ohms, and our standard battery 1.1 volts ; then we have for the value of r for one volt :

$$1 = \frac{1.1}{1,375}r, \text{ from which } r = 1,250.$$

Then we could build a direct-reading voltmeter by making the variable resistance coils as follows :

For	1.00	volt,	1,250	ohms.
"	.50	"	625	"
"	.20	"	250	"
"	.20	"	250	"
"	.10	"	125	"
"	.05	"	62.5	"
"	.02	"	25	"
"	.02	"	25	"
"	.01	"	12.5	"

In a direct-reading voltmeter constructed upon this principle the electrical connections and resistances would be as shown in Figs. 8, 9, and 10.



We will assume that our standard battery has an electro-motive force of 1.36 volts, and that our fixed coil has a resistance of 1,360 ohms. Let us build our voltmeter to measure electro-motive forces from 6 to .01 volts. Then our variable resistance coils will be 2,000, 2,000, 1,000, 500, 200, 200, 100, 50, 20, 20, and 10 ohms, respectively; corresponding to 2, 2, 1, .5, .2, .2, .1, .05, .02, .02, and .01

volts. The terminals of the source of electro-motive force to be measured are connected, the positive to terminal *A*, and the negative to terminal *B*. The main circuit is opened at some point, *C*, and the terminals connected to the upper contacts of a double contact key. The galvanometer circuit is opened and the terminals taken to the lower contacts of the key. In this manner the standard battery circuit is kept open until the key is depressed.

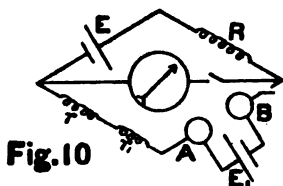


Fig. 10

Let us see if a direct-reading voltmeter can be constructed upon the principle of the special case where $E_1 = E R \frac{1}{r}$. We will give to the fixed resistance *R*, as before, such a value that the product *ER* shall be unity or some decimal of unity, for instance, 1,000. Then for

1.00 volt,	<i>r</i> =	1,000	ohms.
.50 "	"	2,000	"
.20 "	"	5,000	"
.20 "	"	5,000	"
.10 "	"	10,000	"
.05 "	"	20,000	"
.02 "	"	50,000	"
.02 "	"	50,000	"
.01 "	"	100,000	"

But a voltmeter built in this manner, of coils ranging from 1,000 ohms to 100,000 ohms for the fixed resistance, would not be direct-reading. For instance, suppose the battery to be measured had an electro-motive force of .7 volt, the resistance would be intermediate between 1,000 and 2,000 ohms, but we have no such coils or combination of coils that would give the desired resistance.

One way to obtain a direct-reading voltmeter with this arrangement is to make a slide resistance out of our variable coils, requiring for a range from 1 volt down to .01 volt 100 distinct coils and over 100,000 ohms resistance. We could in this manner make a direct-

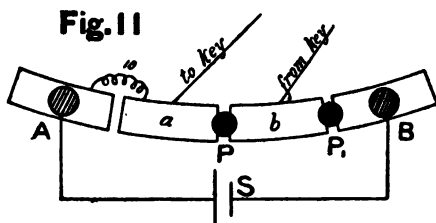
reading instrument, but it would be difficult of construction as well as expensive.

BATTERY RESISTANCE.—In all battery work it is necessary to know the resistance, as well as electro-motive force of the battery. For this purpose the battery whose resistance we wish to measure is connected to a working resistance, and the electro-motive force at its terminals measured, its electro-motive force on open circuit having been previously determined. These two measurements enable us to compute its resistance. Let B represent a battery shunted by the resistance R . Let r represent the resistance of the battery. Let E represent the electro-motive force of the battery on open circuit, and E_1 the electro-motive force at the terminals of the battery when shunted by the resistance R . From Ohm's law we have

$$E = (R + r)C; E_1 = RC, \text{ from which, } C = \frac{E}{R + r} = \frac{E_1}{R}$$

And by transposition and reduction we have $r = \frac{E - E_1}{E_1} R$.

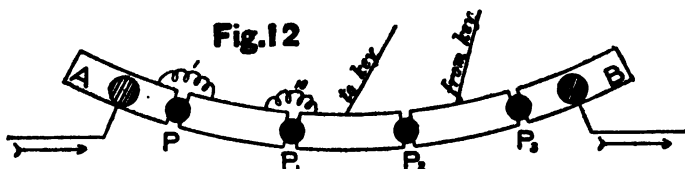
Therefore, we can obtain the resistance of the battery by subtracting its electro-motive force on closed circuit through R ohms from its electro-motive force on open circuit, dividing the remainder by the smaller electro-motive force, and multiplying the result by the resistance of the working circuit. By making the resistance of the working circuit equal to 10 ohms the process is very much simplified. It is necessary to get the value of E_1 , the electro-motive force upon closed circuit, upon the instant of closing the circuit through the working resistance on account of polarization. To do this by means of the direct-reading voltmeter it will be necessary to use a triple contact key, and provide some means of opening the 10-ohm coil when not in use. It may also be desired to keep the 10-ohm coil closed for a definite length of time around the battery terminals without the use of the key. This is effected thus (see Fig. 11):



S is the battery whose electro-motive force and resistance is to be measured. *A* and *B* are the terminals of the voltmeter, the remaining portions of the voltmeter not being shown. One terminal of the 10-ohm coil is connected to *A*, and the other goes to the adjacent brass strip *a*. A connection is carried from *a* to the upper contact of a triple contact key, and a lead taken back to the second strip *b*. With plug *P* removed it will be seen that when the triple contact key is depressed, the 10-ohm coil will be introduced between terminals *A* and *B*, and with plugs *P* and *P*₁ inserted the 10-ohm coil can be kept in circuit around the terminals of the battery for any desired time. With plug *P*₁ removed the 10-ohm coil is evidently inoperative. This arrangement accomplishes, then, the three ends desired, and we have combined in one instrument both a voltmeter and an instrument for determining the internal resistance of batteries.

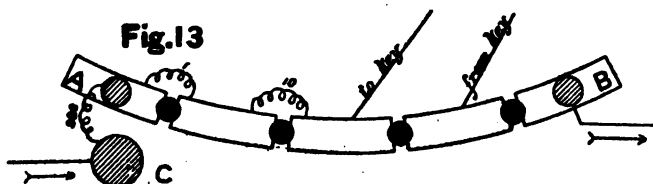
AMMETER.—In many cases we do not care to know the electro-motive forces of batteries, or their resistances, but a quantity dependent upon both of these factors. We wish to know the current of electricity which they will send through a given resistance. It is also of great value to know the current flowing through a given system, say a telephone transmitter, an incandescent or an arc lamp. The addition of one more coil to the instrument, as described, will convert it into a direct-reading ammeter, the figures before denoting volts now registering amperes.

Let us see how this is accomplished. From Ohm's law it follows that if we have a current of one ampere flowing through one ohm, it will generate a difference of electric pressure of one volt at the terminals of this resistance. Now, if between the terminal *A* and *B* of our voltmeter we connect a 1-ohm coil, and if we send a current of one ampere through it, the voltmeter will register one volt. Conversely, if our voltmeter registers one volt we know that a current of one ampere is flowing through the circuit of which the 1-ohm coil forms a part. This coil should be placed in our combination instrument above described, adjacent to the 10-ohm coil, added for battery resistance measurements, the connections being as shown in Fig. 12.



A and *B* represent, as before, the terminals of the voltmeter proper. By inserting plugs P_1 , P_2 , and P_3 , P being removed, it is apparent that we have one ohm from *A* to *B*. We have, therefore, with the additional 1-ohm coil, three instruments combined in one, a voltmeter, an ammeter, and an apparatus for measuring the internal resistance of batteries.

HIGH VOLTAGE.—It is perfectly practicable to extend our voltmeter to high voltages. For ordinary battery work a range from .01 to 6 volts is all that is necessary, the coils required for the variable resistance being 10, 20, 20, 50, 100, 200, 200, 500, 1,000, 2,000, 2,000 ohms. To extend the range to 100 volts five additional coils would be required of 5,000, 10,000, 20,000, 20,000, and 50,000 ohms, respectively. The only objection to the use of these coils is the expense of the wire, which would be considerable for such high resistances. To obviate the necessity of employing these coils for high voltage I have substituted the following device (Fig. 13).

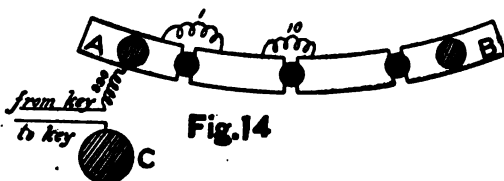


An auxiliary coil of 990 ohms is added to the apparatus. One end of this coil is connected to the *A* terminal of the voltmeter proper, and the other end is connected to the isolated binding post *C*. The terminals of the source of electro-motive force that we wish to measure are connected to this binding post and the *B* binding post of the voltmeter. The plugs between *A* and *B* are arranged so as to throw the 10-ohm coil in circuit between *A* and *B* when the key is depressed.

This is the same arrangement that would be used in the second measurement for battery resistances.

It is evident that we have in circuit between the terminals *B* and *C* 1,000 ohms when the key is depressed, and that there are 10 ohms of this resistance included between the terminals of the voltmeter proper. Consequently, $\frac{1}{100}$ part of the electro-motive force between the terminals *B* and *C* will be included between *A* and *B*. It follows that if we measure the electro-motive force between *A* and *B* by our voltmeter proper under these circumstances, and multiply this voltage by 100, we shall have the total electro-motive force between *B* and *C*. It is only necessary, then, for high voltages to use terminals *B* and *C*, and to move the decimal point of the voltmeter reading two places to the right.

RANGE OF THE APPARATUS.—We can with perfect safety measure up to 200 volts in this manner, by properly constructing our 990-ohm coil and the 10-ohm coils, but for higher voltages it is better to sacrifice somewhat on our battery resistance measurements, and make the connections thus (Fig. 14):



In this manner any slight resistance which might be introduced by oxidation of the contacts from sparking at the key would be thrown into the 990-ohm coil rather than into the 10-ohm coil. The instrument could still be used for determining battery resistance, the 10-ohm coil being introduced manually.

The following data will indicate how the range of the instrument can be extended so as to cover any voltage used commercially, even those employed in arc lighting. It is evident that some of the values given cannot be realized in practice, but there is no difficulty in selecting a combination that will cover every case desired.

Fixed resistance R , 1,000 ohms $\pm$ or $-$

Variable Resistance.	9990-Ohm Coil. 10-Ohm Shunt.	4990-Ohm Coil. 10-Ohm Shunt.	2490-Ohm Coil. 10-Ohm Shunt.	1990-Ohm Coil. 10-Ohm Shunt.
<i>Ohms.</i>	<i>Volts.</i>	<i>Volts.</i>	<i>Volts.</i>	<i>Volts.</i>
2,000	2,000	1,000	500.0	400
2,000	2,000	1,000	500.0	400
1,000	1,000	500	250.0	200
500	500	250	125.0	100
200	200	100	50.0	40
200	200	100	50.0	40
100	100	50	25.0	20
50	50	25	12.5	10
20	20	10	5.0	4
20	20	10	5.0	4
10	10	5	2.5	2

Fixed resistance R , 10,000 ohms $\pm$ or $-$

Variable Resistance.	9900-Ohm Coil. 100-Ohm Shunt.	4900-Ohm Coil. 100-Ohm Shunt.	2400-Ohm Coil. 100-Ohm Shunt.	1900-Ohm Coil. 100-Ohm Shunt.
<i>Ohms.</i>	<i>Volts.</i>	<i>Volts.</i>	<i>Volts.</i>	<i>Volts.</i>
10,000	100	50.0	25.00	20.0
5,000	50	25.0	12.50	10.0
2,000	20	10.0	5.00	4.0
2,000	20	10.0	5.00	4.0
1,000	10	5.0	2.50	2.0
500	5	2.5	1.25	1.0
200	2	1.0	.50	.4
200	2	1.0	.50	.4
100	1	.5	.25	.2
	210	105.0	52.50	42.0

9990-Ohm Coil. 100-Ohm Shunt.	4990-Ohm Coil. 100-Ohm Shunt.	2490-Ohm Coil. 100-Ohm Shunt.	1990-Ohm Coil. 100-Ohm Shunt.
<i>Volts.</i>	<i>Volts.</i>	<i>Volts.</i>	<i>Volts.</i>
1,000	500	250.0	200
500	250	125.0	100
200	100	50.0	40
200	100	50.0	40
100	50	25.0	20
50	25	12.5	10
20	10	5.0	4
20	10	5.0	4
10	5	2.5	2

Used as an ammeter by the employment of a 1-ohm coil, we have seen that its range is from .01 to 6 amperes, and where the introduction of 10 ohms into the circuit is not objectionable, the 10-ohm coil used for battery tests can be employed in place of the 1-ohm coil, and the range would be in this case from .001 to .6 amperes. The following data give the range of the instrument with various coils:

10.0000 ohm-coil.	Range	.001 to	.6 amperes.
1.0000	"	.010	6.0
.1000	"	.100	60.0
.0100	"	1.000	600.0
.0010	"	10.000	6000.0
.0001	"	100.000	60000.0

These figures are somewhat delusive, however. For instance, take the .001 ohm-coil, 6,000 amperes would cause a waste of 36,000 watts, or 48 electrical horse-power, in our voltmeter alone. On the other hand, we could easily measure 1000 amperes with this coil properly constructed, the loss in this case being only a little over one horse-power. An intelligent use of the above coils will enable us to cover nearly every case in practice. For special work a more delicate galvanometer, enabling us to measure to .0001 volt, might be employed. It is evident, then, that the apparatus can be constructed so as to cover any range of current strength or electro-motive force desired.

In criticism of the instrument the objection might be raised that there is no battery of sufficient constancy to be employed with the apparatus. It will be observed, however, that it is not necessary to use a standard battery, but only one that shall remain constant for a considerable time. The best battery to employ would be some form of Daniells cell, were it sufficiently portable. I have used a modification of the Daniells cell for two years with a stationary battery testing apparatus of this type with perfect success. A comparison of the battery with the Latimer-Clark cell at various times has shown a variation of less than one per cent. For convenience, however, it is necessary to use some form of dry battery. I first used a chloride of silver battery of about 20 ohms internal resistance, but found its resistance to be too variable for the desired accuracy of one per cent.

The cell that I am now using has a resistance of two ohms, and has been entirely satisfactory up to the present time. To check the accuracy of the instrument all that is necessary is to have at your disposal a Daniells cell. Should you have any reason to suppose that your instrument is out of adjustment measure the electro-motive force of your Daniells cell by it, and should it differ from the known value of the electro-motive force of this cell, add or remove from the adjusting coil a few inches of wire until you get the desired reading of your voltmeter.

From my own experience with the instrument I think this adjustment will seldom be necessary.

MEETING 399.

Electrical Purification of Sewage.

BY MR. FRANK M. GILLEY.

The 399th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, February 13th, at 8 P.M., Prof. T. M. Drown in the chair.

After the reading of the records of the previous meeting, the chairman introduced Mr. Frank M. Gilley, of Chelsea, who read a paper on "Electrical Purification of Sewage."

MR. GILLEY said: The treatment of sewage was attempted over a century ago, and the chemicals employed at that time were almost identical with those in use today, sulphate of iron and lime. England has lead in this work. Her cities are so populous and near together that the introduction of systems of drainage removed a nuisance farther down the stream. Rivers, or streams as they would be less pretentiously called, became filled with sewage deposit, the fish in them died, and the general poor health and discomfort of those who lived

on or near the banks called attention to the absolute necessity of removing or abating such nuisances. The removal consisted in the application to land or the discharge of the sewage into the sea or farther down the brook or river flowing through the town, perhaps near some other town. In many cases the nuisance was abated, never removed entirely, by the use of chemicals, and the precipitation of most of the suspended matter, and the destruction or oxydation of a little of the organic matter in solution. Suspended matter must either be deposited in settling tanks as sludge or in some river or harbor as mud until dredged out. The organic matter is the most difficult to destroy or remove, and is the part most dangerous to health. The oxydation of the organic matter can be accomplished by one method only, chemical action, whether that be produced by filtration, the addition of chemicals, or electrolytic action. A filter is sufficient when employed intermittently, for then the filtering material becomes aerated, *i. e.*, charged with atmospheric oxygen during the periods of rest; and this oxygen destroys the organic matter of the sewage. Oxydation can also be accomplished more or less expensively by chemicals. The electrical method differs from the above methods in two points; first, the oxygen and chlorine that produce the burning up or oxydation of the organic matter is made by decomposing, by the aid of a current of electricity, the water and chlorides of the sewage itself; second, the oxygen and chlorine act much more powerfully at the moment of their formation, being set free in what is called a "nascent" state.

Mr. Wm. Webster, F.C.S., engineer and contractor for the construction sewage works, including precipitation tanks, during a series of successful experiments in the purification of sewage by electrolysis, settled at last upon two metals suitable for electrodes, aluminum and iron, the latter, on account of its cheapness, practical on a commercial scale. He first tried large tanks in which the liquid was treated and allowed to settle.

Strips of sheet iron are placed in a jar of sewage and a current passed through the solution. Hydrogen is given off from the plate connected with the zinc pole of the battery, and from the positive pole, *i. e.*, the strip where the current enters, chlorine and oxygen are set free in a "nascent" state, probably combining with the iron to form a hypochlorite of iron which is immediately reduced to ferrous car-

bonate and oxide. If there be no dissolved *O* in the water the white oxide is produced. But in any case the color is soon green, and finally red, ferric oxide (Fe_2O_3). On a small scale, or where there is no current or agitation, the precipitate buoyed up by the hydrogen is brought to the top together with the particles in suspension, and finally sinks. If overtreated, the filtrate or effluent, as the clear liquid is called, has a reddish tint from the presence of ferric oxide. The solid matter, or sludge, has little or no liability to decompose, but, of course, must be disposed of in some way, ploughed into land, pressed and sold or given away as a fertilizer, or taken out to sea.

The E. M. F. between the plates is at least .9 volt when of iron, 1.5 when of carbon. In practice London sewage requires one ampere per gallon for 10 minutes, or less than $\frac{1}{4}$ ampere an hour per gallon. More current would supercharge the liquid with iron salts. A slight greenish tinge and evident separation of the suspended matter are the signs of sufficient treatment. The color on leaving the sewer is nearly white and opaque. After treatment the *liquid* is clear and filled with the particles of sludge, which deposit quickly when allowed to rest for a few moments. Owing to the resistance of contacts and the liquid itself, about 2 volts is the difference of potential of the plates, and about 1 ampere per 5.5 square feet of iron surface exposed. In larger units, 23 h. p. in 24 hours treat 7,000,000 gals. of London sewage.

It may be advisable to pass the effluent through an electric filter composed of alternate layers of coke carbon and sand or porous earthenware, the coke being electrically connected in alternate sections to positive and negative terminals of a dynamo. No increased power is required, for when the electrical filter is used the treatment with the iron plates is not carried so far. The same device is also applied to household filters for drinking water, the contamination of which with sewage or vegetable organic matter is always to be feared, and water of purity as regards organic matter and living organisms produced easily. A few open circuit cells furnish sufficient current which, on account of the resistance of the water, is small and does not flow at all while the filter is not in use.

Where brackish or salt water can be obtained by the means of a porous diaphragm, a disinfecting fluid containing 18 grains chlorine per ampere per hour is made. The positive plate must be of carbon, the negative may be of iron. If in the porous jar containing the car-

bon a piece of iron be connected also, a hypochlorite of that metal is made and may be used for the same purpose as the chlorine alone. One-third grain of chlorine is found to disinfect one gallon London sewage. By automatic attachments such an apparatus is used in the household, and the liquid supplied and drawn off at intervals when needed for use. The ordinary Leclanché cells, five or six in number, will last several months and produce two gallons of chlorine solution daily.

Mr. Webster's experimental station is located at Crossness about 13 miles from London. The sewage is pumped into a shoot 18 inches square, 400 feet long, and, filled with wrought iron plates in groups of 15, a large number of which connected in multiple or parallel form sections in series with each other. A space of two or three feet in the shoot between sections is sufficient to prevent undue leakage. The 70 h. p. Mather and Platt dynamo gives 20 volts. The six sections take approximately 3 volts per section, current 320 amperes. It would be economical as regards the loss in the conductors to have more sections in series, but the number is limited to 25 or 30 on account of danger to the workmen, it being impossible to avoid grounds, as both ends of the shoot have liquid connection to the earth at the inlet and outlet. The consumption of the iron plates is from 1 to 2 grains per gallon of sewage treated if cast iron is used. Wrought iron scales badly and is more expensive, but from its lightness is well adapted to experimental work. The velocity in the shoot is about 10 to 25 feet a minute, or from 4,000 to 10,000 gallons per hour. The color shows no apparent change for 20 to 30 feet, then numerous bubbles come to the surface, and farther on these have a brown color, and near the end the liquid is dark. At points in the shoot the current runs over or under an adjustable board, giving a thorough mixing and a complete control of the level in each section of the shoot. It is desirable that the outlet should be below the level of the liquid in the precipitating tank that it may settle rapidly and to a compact form. As the churning action in the shoot has liberated all of the hydrogen, the precipitate settles at once, and in two hours the clear effluent may be drawn off and discharged directly or through an electric filter into any convenient stream; or without settling it may be run on to land which does not become clogged, and the precipitate or sludge rapidly drying on the surface is easily worked into the land. The sludge as

taken from the tanks forms .7 per cent of the total sewage, and, after remaining in a settling tank, is reduced to .4 per cent of the original amount treated. It then contains 90 to 95 per cent of water, and must be disposed of in some way. Deprived of 50 per cent of this water by presses (and the sludge formed by electrical treatment is better adapted than any other for the press), and 20 per cent more by drying, it is worth, by analysis, \$10 per ton; but in any case should pay for carting.

Cast iron is thought to have an advantage over wrought iron in the larger per cent of carbon it contains, which results in the production of chlorine. The size is limited only by the possibilities of manufacture. Six feet by 8 feet by $\frac{3}{4}$ inch plates are said to be made for other purposes by French engineers. The metal dissolves evenly, any projecting portions offering less resistance and being more acted upon by the current. Though only $\frac{1}{4}$ inch apart the plates showed no signs of blocking, and the entire shoot can be emptied in 15 minutes for cleaning.

A test at the time of my visit was in progress by the chemists of the London County Council, and the consumption of iron determined by weighing the plates before and after a long run, and analyses made of the crude sewage and effluent. It must be remembered that such a reduction of the organic matter is desired as shall abate the nuisance that exists in the river. Perfect purification, nor anything approaching that, is not desired. 70,000,000 gallons at Crossness, and 90,000,000 at Barking is a large amount to treat by any system, but the attempt is being made by the addition of 3.7 grains of lime and 1 grain of sulphate of iron per gallon, and the effluent disinfected by permanganate of soda manufactured at the works. The discharge is supposed to be at ebb tide, but takes place practically all the time that the water in the river is low enough. The manganate of soda and sulphuric acid are added just before discharge. Notwithstanding this treatment, complaints of the condition of the river are continually made. The amount of chemical used seems insufficient, for other cities used 10 to 20 grains instead of 5. But for all that between two and three million dollars is being spent on immense precipitating tanks at both the outfalls, with the view of extending the chemical treatment to the entire sewage discharge. These tanks, with some changes, can be made to serve for the electrolytic process of treatment when that is finally adopted.

The plant that Mr. Webster has built at Crossness to test his system is only relatively experimental, having a capacity of 500,000 gallons a day, and by extending or enlarging the shoots, 1,000,000 gallons, for which there is sufficient room and power. At 80 gallons per head per day this would be ample for a town of 80,000 inhabitants in England. In the United States the sewage is larger in quantity but more dilute, requiring larger shoots and more iron surface, *i. e.*, a somewhat greater first cost but about the same operating expenses. In England the cost of a 1,000,000 gallons a day works, with duplicate engines and dynamos and iron plates lasting ten years, is estimated at \$80,000, or \$1 per inhabitant, but would be materially less here, if the cost of steam and electrical machinery and contract construction work in the two countries furnishes any basis for comparison. The expense of 800 pounds of iron daily consumed has been estimated in the cost of the plant, and the labor of four men and the consumption of a ton of coal or less make a daily expense of \$13. A visitor at the station is invariably impressed with the success of the system, no unpleasant odor is perceptible, and the appearance of the sewage during treatment and precipitation is far more inviting than the surface of the streets of the crowded parts of even Boston. The epicures of London may be looked upon as opposed to this system, for, according to Lawes, the fish of the Thames feed on the sewage; and where will the tempting and luscious whitebait, that is now taken only in the Thames estuary, and for which the cuisines of London are famous the world over, find its food and the dredgers find employment if the crude sewage is successfully treated by the electric current?

The paper was illustrated by numerous diagrams and lantern views.

MEETING 400.

Domestic Steels for Naval Purposes.

BY LT.-COM. J. G. EATON, U.S.N.

The 400th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, February 27th, at 8 P.M., Prof. R. H. Richards in the chair.

After the reading of the records of the previous meeting the chairman introduced Lt.-Com. J. G. Eaton, U.S.N., who read a paper on "Domestic Steels for Naval Purposes."

Mr. EATON said: Within the scope of this paper lies properly a rapid retrospect of the history of domestic steels, with a view of understanding fully the marvelous development that has occurred within the past seven years. The uses we are to consider are those strictly germane to ships of war, and include not only hulls and hull material, but boilers, engines, rigging, guns, and armor.

Proceeding in chronological order we find that in 1865 the Pennsylvania R. R. Co. made efforts to secure flange plates of American steel for its locomotive boilers. The steel then used was crucible steel, made by a Pittsburgh firm. So satisfactory were the results that in 1866 this company built no less than eleven locomotive fire boxes of the same material. In June, 1866, was built the first locomotive boiler entirely of domestic steel, crucible made and of high cost. At this time the Bessemer process was but just established in the United States, and the open-hearth process not yet introduced. Despite the evident superiority of the new material, it was not until 1873 that steel wholly superseded iron for boiler purposes, even in this company.

In the navy a high grade of steel was used for steam launch boilers in 1872, but it was not until the spring of 1878 that the first large marine boiler of steel was placed on board the fish commission steamer "Lookout," and the "Nipsic" was the first American man-of-war to be thus equipped, in the fall of the same year.

For structural purposes crucible steel, hardened by an alloy of chromium, was employed in the Eads St. Louis bridge in 1869. Though successful in all respects, the experiment has not been repeated.

Practically, mild steel for bridge building dates from 1879, when Bessemer plates and girders were incorporated in the approaches to the East River bridge. From this date also open-hearth steels entered largely into bridge structures. None of the bridge steels of that time would now be called mild steel, as the T. S. was from 70,000 to 80,000 lbs. per square inch, and the elongation only 20 per cent in 8 inches. The total amount used was small, as the aggregate of all classes, crucible, open hearth, and Bessemer, was but 18,000 tons in the fifteen years from 1869 to 1884.

In ship building we did nothing whatever prior to 1879. In that year three vessels of an aggregate tonnage of 246 tons were built for river navigation. Up to 1883 five more, including lighters, were constructed. The total tonnage to this date was less than 500 tons. All of these vessels were steel plated only. Practically, then, steel ship building was an unknown art, the material untried, and the workmen unskilled, when the frame of the "Dolphin" was laid down in 1883.

Such was the status of the steel industries as regards structural material when Congress authorized the construction of our four first ships of mild steel of domestic manufacture. The courage and foresight of the Advisory Board of Naval Officers, upon whose recommendation Congress acted, are entitled to recognition. Iron ship building was already an established industry, and its results certain. As to steel (this was in 1882), there were difficulties in production, as yet imperfectly understood, and but partly overcome. There was the still more serious objection of the utter lack of workmen skilled in the manipulation and assembling. The compelling reasons leading to the Board's decision are here given:—

1. Great saving in weight of hull, compensating for difference in cost.
2. Increased strength in hull.
3. Increasing success attending construction of steel hulls abroad.
4. The certainty that steel in the near future is to supplant iron in ship construction. (A prophesy virtually fulfilled.)

5. The impetus that such a step taken by the government would give to the general development of steel industries in this country.

6. The necessity that the new ships shall in all respects equal, if not excel, ships of other navies, class for class; and,

Finally, that for the reputation and the material advantage of the United States, it is a prime necessity to take a bold and decided step to win back from Europe our former prestige as the best ship builders in the world.

From these seven patriotic, courageous, and far-seeing conclusions the navy has never receded. The success of the new vessels has evidenced their wisdom, and the merchant marine has been quick to follow the initiative.

Quality and cost were undetermined factors. The specifications were high, and the requirements rigorous. Replying to circular letters, the manufacturers expressed confidence as to the quality of their steels, but doubted their ability to supply the special shapes required. It is a somewhat caustic commentary on the actual capabilities of the time that the quality failed, though sections were up to standard.

At this time the largest ingots were of five tons, the heaviest plates but $1\frac{1}{4}$ " , weighing about three tons each. Thirty feet long I beams of 12" section almost stalled the heaviest rolls. At present the Bethlehem Iron Co., of Bethlehem, Penn., are casting ingots of 100 tons weight, and are producing curved plates $17\frac{1}{4}$ ' x 6' x 17" thick, and 16' x 9' x 12" thick, weighing 36 tons each, finished. There are at least six other firms who are now prepared to furnish plates up to four inches in thickness.

The specifications which were drawn up in June, 1883, called for mild steel for hulls with T. S. of at least 60,000 lbs. per square inch, and elongation of not less than 23 per cent in eight inches. Boiler plates specified not less than 57,000 lbs. nor more than 63,000 lbs., with a ductility of at least 25 per cent.

Under these specifications contracts were entered into for the construction of the A, B, C, D ships in July, 1883. Three of these ships, the "Atlanta" and "Boston," of 3,000 tons displacement each, and the "Chicago," of 4,500 tons, have recently visited this port. Since then they have weathered storms of unusual winter severity in crossing the Atlantic, and are now in Europe. The D, the Dolphin, a dispatch boat of 1,500 tons, has recently refitted in New York, after

a voyage of over 45,000 miles around the world. That these ships have shown themselves equal in construction and material to the strains and service for which they were designed has been abundantly proved. During the construction of these vessels a determined effort was made to break down the system of naval tests and inspection. The reasons assigned were impracticability and expense. Delays were not only exasperatingly frequent, but failures also were many. The specification as to ductility was lowered to 21 per cent, and some slight modifications made as to methods. The system then established is the foundation of our present inspection. Each new vessel is built of better material than her predecessor, and the requirements keep in advance of the material. In 1886 the Steel Board succeeded the Advisory Board, and has for its function the inspection of all steel material for hulls and machinery.

Attention was called to tables on the board which showed the increasing severity of the specifications, and the changes due to experience.

In hull plates and shapes we find the tensility constant at 60,000 lbs., but the additional safeguards of chemical conditions and surface inspection, aided by additional tests, serve to show the good or bad quality of the material better than either T. S. or elongation.

Up to 1876 steel was generally accepted on the maker's guarantee. From that time, however, testing of steel, particularly boiler steel, came in. The features of the Pennsylvania R. R. Co.'s inspection, which are quoted as being the most thorough before the navy inspection began, were:—

1. Careful examination of every sheet for mechanical defects.
2. Tensile test; 55,000 lbs. per square inch, ultimate strength. Elongation; 30 per cent in 2 inches. Both of these were averages. The limits were: tensile, minimum 50,000 lbs.; maximum 65,000 lbs.; elongation, minimum 25 per cent.
3. Rejection of sheets developing defects in working.
4. Coupon tests for each sheet.

No conditions were imposed on impurities beyond those which the manufacturer knew would affect surfaces, and cold or hot shortening.

The inspection of steel for naval purposes contemplates that the inspector should thoroughly familiarize himself with the composition of the furnace charges. As the variations in the pig and mill irons,

blooms, crop ends, scrap, and ore that go to make up the charge are recorded in the resulting steels, the inspector should possess a fair knowledge of the chemical composition of each ingredient. Chemical analysis of the resulting heat is invaluable, but even this fails to give warning of certain conditions which can be presaged from the characteristic of some component charged. Forearmed with this knowledge, he may avail himself of the extra tests allowed at his discretion, and either justify his suspicions by patent proof and reject the heat, or assure himself that the material is good.

Acid open-hearth furnaces run two heats daily. Basic furnaces can as easily run four in the same time. A heat may contain three tons, or fifty tons of metal, according to the size of the furnace. The melted steel is usually tapped into a ladle previously heated, and thence into ingot molds. Ingots vary in weight from 500 lbs. to 200,000 lbs., and in cross-section from 2" x 2" to 50" x 72". They are either top-cast by pouring directly into the mold, or bottom cast by stand and runners. Whilst the heat is being turned, and near the middle time, tests are secured for chemical analysis. Tests may also be taken at the beginning and end. Should these tests exhibit wide variations, then each ingot must be tested independently. From the ingots the inspector selects the poorest four for his test plates. Here, as elsewhere, his duty is to secure the worst specimens, and make these his indices as to quality. The ingots chosen are taken to the heating furnaces and there raised to the proper working heat, determined by the heater's eye, the color ranging from a light yellow to white according to the per cent of carbon. This is a critical operation, as an over-heated or burnt ingot will cause enlarged crystallizations, pits, and laminations in the finished product. Insufficient heating will either break the rolls or cause cold flow, setting strains in the plate or shape, which can only be restored to an amorphous condition by thorough after annealing. No amount of after mechanical work will reduce coarse crystallization.

SURFACE INSPECTION.—The plate or shape as it issues from the rolls should be inspected whilst still hot. Most surfaces are covered in a short time with red or black oxides and mill scale that effectually conceal serious defects. Pickling serves to bring these to light, but immediate detection not only safeguards any possibility of error, but obviates much unnecessary expense. The principal surface defects

are pitting, scabs or blisters, hair cracks, scale marks, snakes, cobbles, and laminations. Probably 75 per cent of surface defects are due to pits. Pits are conical cavities, base uppermost, pocking the surface. If their depth is at all considerable the plate is ruined. Their cause has already been stated. Should cinder or fine brick from the heating furnace be rolled in, a spotted appearance will give indication. A sharp tap of the long-handled hammer carried by the inspector will dislodge the extraneous substance, and disclose the extent of the injury. Bits of slag are discovered by hair lines. Scale cools more rapidly than the plate itself, and produces hummocks. Cracks are found in the direction of rolling, and indicate imperfectly welded blow-holes long drawn out. Test transverse specimens to ascertain their injury. Snakes, on the contrary, as their name implies, are twisted in every direction. Their appearance strongly resembles a water mark in paper, and they are visible only in favorable lights. They are, undoubtedly, caused by the presence of low forms of iron, peroxides, or protoxides, generated by burned metal in the furnace, and separate two masses of pure steel. No amount of work, heat or mechanical, will effect a true weld across this filmy barrier. Once in the ingot, snakes reappear inevitably in the plate or shape. An ingot known to be snaked is at once thrown aside to be scrapped. Snaked material is utterly lacking in homogeneity, and no material for structural, boiler, or engine purposes should be accepted which is even suspected of this defect. Crucible and basic steels are nearly exempt from this evil. Radiating furnaces should prevent them entirely.

Laminations occur at the surface and upon the edges. Surface laminations are due to chipping ingots, the cavity thus formed being covered by overlapping edges. A few taps of the hammer will cause these overlaps to separate into sheets. Plates should be inspected for laminations after shearing.

Cobbles are waves in a plate caused by unequal heating of the sides of an ingot. Under an equal draught from the rolls the hotter side creeps faster, thus producing ridges. There is no remedy for this defect. Cobbles are recognized by the diagonal trend of the ridges. Simple waves at right angles to the longitudinal axis are not serious. They are caused by unequal cooling on the train rolls.

SHAPES.—The surface inspection of bulb-beams, angle, T, and Z bars is much simpler than that of plates. The blooms, slabs, or

ingots from which they are rolled have smaller sections, permitting more even heating and better cleaning in the rolls. Unsymmetrical sections are found, and many run scant near the ends. In bulb-beams especially the angles are frequently cold drawn by the more rapid travel of the metal in the web, due to its receiving a great deal of work after the flange is fairly formed. Again, over 50 per cent of the metal is below the neutral axis of the web. The cold flow causes wire edges, and sets strains that in many cases equal the strength of the metal. A beam thus rolled might shiver to pieces, like brittle glass, on being thrown from a platform car. Proper annealing will do much to restore the metal to a state of intermolecular equilibrium. Unsymmetrical angle bars, 5" x 8", etc., also suffer from the same cause. To be absolutely certain that these strains are removed, annealing should be resorted to. The apparent loss in ultimate strength is more than compensated for by the gain in homogeneity.

TEST SPECIMENS.—The navy standard specimens for structural and boiler material are 16 inches long, not over 2 inches in width, with a cross-section of not less than five-tenths nor more than eight-tenths of an inch. The witness marks are 8 inches apart. For engine forgings, protective deck, ordnance and armor plate, a filleted round is prepared, section not over one square inch, and 2 inches between the witness marks. Other things being equal, this specimen will give 80 per cent greater elongation than were the witness marks 8 inches apart. Four test specimens are taken from each of the four test plates. This permits duplication in case of faults in the specimens themselves. Recalling that ingots are tapered to facilitate stripping, and that the bottom of the ingot has not only a greater cross-section, hence greater reduction and more work under the rolls, but also that the steel is more compressed and freer from sponginess at the bottom, the inspector takes these specimens from the top and sides. The object in view is to obtain specimens that shall show not the average condition, but the *poorest* part of the finished material. Here, as always, the inspector is on the alert for the worst features. There is no average strength for a steel plate. Its true strength is the value of the weakest inch of its contents.

Tensile strength and elongation vary in the same plate. Thus, a remarkably well rolled plate at the Homestead Steel Works at Pittsburgh rose from 49,000 lbs. T. S. at top end to 51,800 lbs. T. S.

at bottom end, or 6 per cent. The taper of this ingot gave 26 reductions for top end to 27 reductions for bottom. The elongation fell from 32.7 per cent at top to 29.8 per cent at bottom, or 10 per cent. The value of this plate was evidently the minimum in each case.

The larger the ingot the more essential the selection of specimens from the top. Segregation of the metalloids increases with increase of size, as large ingots, presumably, cool slowly. The temperature at which the heat is termed is, however, of greater importance. Surprising variations occur in chemical condition in same ingot. Thus, two specimens taken from the opposite ends of the same plate rolled from a slabbed ingot, and a slabbed ingot has already lost by shearing its worst end, gave:—

	T. S.	Elongation.	Reduction.	Carbon.	Phosphorus.
Top end, . .	64,500	19 per cent.	81 per cent.	0.31	0.075
Bottom end, .	55,400	26 "	48 "	0.17	0.050
Heat test, ...				0.15	0.044

A result sufficient to condemn at once the material for ship building. In cold bending the top specimen broke short off with fracture, indicating high carbon and phosphorus, and showing weak, large crystals. The bottom specimen closed upon itself without a crack.

TESTING SPECIMENS.—The test piece selected for breaking is carefully measured with a micrometer reading to thousandths of an inch. From this is computed the original section. Twelve one-inch marks are punched on the edges for elongation data. The specimen is then placed in the machine and the initial stress applied. Additional loads of 5,000 lbs. each are added at intervals of thirty seconds, the beam being kept in equilibrium. The elastic limit is marked by unsteadiness of the beam, ending in a sudden drop. The cracking of the mill scale at this instant is a good though not infallible indication. When the ultimate strength is reached the beam refuses to rise. After this the specimen stretches and necks, until fracture occurs, with a sharp report. The fractured ends are carefully fitted together and measured as before. The comparison of these new measurements with those previously taken gives the percentages of reduction of area and elongation. The ultimate T. S. and elastic limit are calculated from original sections. Elongation varies widely with the location of the fractured section. The nearer the grip the less the elongation; the nearer the center of the specimen the greater.

CHARACTERISTICS OF FRACTURES.—An excellent criterion of the steel is afforded by the form and appearance of the fractured section. Cup-shaped fractures with fine crystallization and uniform gray color, technically termed silky, indicate homogeneous well-rolled metal. Sliding fractures occur frequently but are not so favorable. Irregular jagged fractures are to be distrusted. Mottled, parti-colored streaks, bright spots, dark patches, and coarse crystallization evidence poor metal, and should arouse suspicion however good the tensility and ductility. Blotches and parti-colors point to over-heating; patches and streaks denote segregation and cold rolling; coarse granulation implies insufficient work, high phosphorus, or burned metal. Each impurity in the ore, each atom of mechanical work, each thermal unit, has left its mark writ ineffaceably in the resultant steel, and he who knows may read.

QUENCHING AND COLD BENDING TESTS.—The quenching specimen, raised to a dark cherry-red in a fire free from smoke, is plunged into water at a temperature of 82° F., then is bent cold around a curve three-halves the thickness of the specimen. Properly performed, the quenching test will detect cold rolling, brittleness, and segregation, due to phosphorus. A well rolled plate of good material should close upon itself without cracks. This test is known to the trade as the temper test.

Cold bending requires that the specimen, as it comes from the finished material, should close upon itself without cracks or flaws. Very few pieces fail. Thin pieces readily fold twice without cracking. Good steel, well rolled, will close readily under a trip hammer when under $\frac{3}{4}$ " thick. Heavier specimens should be placed under a hydraulic press, whose slow, regular pressure permits the cold flow of metal. Wide specimens do not bend readily. Rivets are required to be both cold flattened and hot flattened under hammer. Additionally they are bent into a hook.

ADDITIONAL TESTS FOR SHAPES.—The additional tests for shapes are cold-opening, cold-closing, and shocking or percussive. For beams the opening and closing is a single operation. Under a hydraulic press the angle is bent cold until its inner edge touches the web. This test is especially severe on large sections. Much trouble was experienced in testing 9" bulb battery beams for the U. S. S. "Charleston." Most of the original beams broke short off in the web,

close to the fillet. These beams were rolled from unconditioned Bessemer steel, and the fractures disclosed large, weak, fiery crystals. At present all beams are conditioned in that arch enemy, phosphorus, and the metal must be open hearth. Angles must also open and close without fracture. Few fail in opening, the closing test being the more severe. The present drop or shocking test affords an excellent method of judging of the brittleness.

A 5" x 3" x 9' reverse bar of open hearth steel for the armored battle ship "Maine," now building at New York, endured thirty-three blows from a 640-pound weight dropped 5 feet. The bar inverted after each blow was bent over 90°, and showed fatigue after the twenty-fifth blow. When fracture occurred, the steel tore, not split, half across the narrower angle. At this time the bar had lost all semblance to its original shape, being twisted and flattened. Similar tests made with cold punched bars showed that the fractures rarely extended into the holes, though often grazing them. A better material for ship building can hardly be asked. Hulls framed of such metal will endure any amount of battering, bumping, and ramming before breaking.

BOILER PLATES AND STAYS.—All boiler plates must be of open hearth steel conditioned to .035 of 1 per cent of phosphorus, and .040 of 1 per cent of sulphur. Each plate is tested independently and stands or falls upon its own record. Hull plates are tested by heats. Test specimens are cut both longitudinally and transversely, the transverse specimens showing higher tensile and lower elongation. Owing to the greater size of the ingots, due to large and heavy plates, there is more difficulty in proper heating, the outside frequently bleeding before the core is sufficiently hot. This causes more pits and laminations. Thus, the shell plates for the boilers of Cruiser No. 5 were $\frac{3}{4}$ " thick, and weighed finished 5,000 lbs. each. Ingots for such plates would weigh from 8,000 to 10,000 lbs. The economy of fuel in high pressure boilers has already forced us a long way in increase of strength of material. Our new cruisers, with boilers 15' 9" diameter, working under pressures of 160 lbs., show how far we have progressed. The introduction of high tensile, high carbon wide shell plates is not entirely devoid of danger. High carbon means less dependence. Plates over 70 inches wide develop defects which narrower plates escape. We shall be told that wide plates are preferable to

many rivetted seams. We concede that these seams are but 70 per cent of the plate strength, but no man knows not how much but how little strength there remains in a wide plate cold rolled. A working pressure of 160 lbs. gives 6 tons to the square inch upon the plates, and about $8\frac{1}{2}$ tons between the rivet holes. As the elastic limit is but 16 tons, it would seem that we had about reached the limit that prudence dictates. The advantages already gained by the use of such a fine material as mild steel are evident.

Corrugated flues found their way into favor in 1878. It is really the adoption of light corrugated steel furnaces that has made possible the present high pressures and temperatures. There has been little trouble in getting a sufficiently strong shell plate even of iron, but with present temperatures in furnaces iron is too apt to blister. Without the increased strength added by corrugation, even steel plates would have been too thick to withstand the heat. As it is, even now, we cannot carry the pressure much above 200 lbs. without coming uncomfortably close to the dreaded blue heat in the furnace plates.

The electric welding people anticipate being able to weld boiler plates, which will be a second saving of weight by doing away with butt straps and rivets. One English firm produces circular weldless boiler plates 48" width by 16' diameter. The British Lloyds reduce the scantlings one-third for these boilers. For equal strength the saving in weight by steel boilers over iron is as 5 to 6. The greatest success to be attained by electric welding will be the welding of tubes to tube sheets. Not only would this be of the greatest service to the type now in use, but it would render practicable many forms of tubulous boilers, well designed for efficiency of heating surfaces and circulation, that fail on account of leaky tubes and complicated bracing.

The factor of safety in boilers has fallen steadily with the rise in pressures. This decrease dictated by necessity is warranted, in part at least, by improved material and superior methods of assembling. From a standard of nearly eight this factor has fallen to four. Efforts are now being made to test boilers to 90 lbs. above working pressures, and design the boiler for this pressure with a safety factor of about two and one-fourth.

In the navy we count the average life of a steel boiler at twelve years, which equals iron. In the merchant service the period would be extended to fifteen years. The cause of this difference is well

known. Our best boiler steel exceeds the best boiler iron in strength about 18 per cent.

ENGINES.—The use of steel in engines is as old as its use in boilers. We find it in the shafting of the Dover mail packets in 1857. These were of puddled steel. The failures of many Krupp shafts (T. S. 80,000 lbs., elongation in 8 in. 14 per cent) in 1863 greatly retarded further advance. In 1880, however, mild steel (T. S. 50,000 lbs., elongation 20 per cent) was introduced. At present we use a T. S. of 60,000 lbs., elongation in 2 in. 28 per cent, and consider 70,000 lbs. as the safe upper limit. All steel for forgings must be made by the open-hearth process, and must not show more than .06 of 1 per cent phosphorus, nor more than .04 of 1 per cent sulphur. All forgings must be annealed and free from cracks, blow holes, hard spots, and foreign substances. The cost of solid forged shafts is very great, as it requires a 42-ton ingot to complete a 17-ton shaft. The Bethlehem Co. now make shafts up to 30 in. diameter, weighing 40 tons each. The saving in weight over iron is about 36 per cent. At present steel is generally used for shafting, piston and connecting rods, valve and reversing gear, various arms, rods, etc.

Cast steel is preferred for engine frames and bed plates, pistons, cylinder and valve chests, bonnets, cylinder liners, etc. Wherever it replaces iron a saving of at least 25 per cent can be reckoned upon.

For tension and ability to resist shock cast steel is one-third stronger than wrought iron; forged steel three times stronger. Similar relative superiority exists in transverse and torsional strength. The steel castings for the gun-boat "Petrel" gave T. S. 72,196 lbs., elongation in 2 in. 32.5 per cent, reduction of area 35 per cent. Specimens bent cold 116° without fracture, and this is cast, not wrought, metal. The advance in ductility in castings has been very rapid. The substitution of cast steel of a ductility superior to old forgings for moving forged portions is already begun.

ANCHORS AND CHAINS.—The anchors for the navy have cast-steel crowns and flukes with forged iron shanks. The requirements for the steel are, after annealing: T. S. 60,000 lbs.; elongation in 8 in. 15 per cent; phosphorus .06 of one per cent. The weight is practically the same as iron, as lessening an anchor's weight lessens efficiency. The gain in strength exceeds 35 per cent.

We have not as yet secured steel chains for the navy, but the

great superiority of mild steel over iron in ultimate strength, elastic limit, and elongation reinforced by electric welding must cause its speedy adoption. Cast-steel chains have been successfully made in England and France, and are sanctioned by the British Lloyds and French Bureau Veritas. We have none of domestic manufacture.

STEEL RIGGING AND ROPES.—For standing rigging, galvanized steel wire is used. The specifications require T. S. 160,000 lbs.; elongation in 10 inches 1.5 per cent; elastic limit 80,000 lbs. Additional vibratory tests are prescribed as follows: angle of vibration 40°; number of vibrations 1,300.

For running rigging and ropes annealed galvanized wire is preferred. Requirements: T. S. 70,000 lbs.; elongation 10 per cent, elastic limit 38,000 lbs.; angle of vibration 40°; number of vibrations 500. Steel is used for military masts and torpedo booms. The requirements are the same as hull steels.

STEEL FOR GUNS.—In 1884 the batteries of U. S. men-of-war were composed of Dahlgren and Rodman muzzle-loading, smooth-bore cast-iron guns of 9 in., 11 in., and 15 in. calibers; 8 in. muzzle-loading rifles, converted from cast-iron smooth bore 11 in. by the insertion of a wrought-iron tube; of cast-iron Parrot rifles with a reinforce hoop of wrought iron shrunk on; and of 60 lb. breech-loading rifles converted from Parrots. No nation upon this globe floated such antiquated, obsolete guns as we. The best of the guns had a penetration of about ten inches of wrought iron at short range, and a total energy of less than 2,500 foot tons. Today we have in service, or approaching completion, high powered breech-loading rifles of 4, 5, 6, 8, 10, and 12 inch calibers. The 6 inch, a light gun weighing only five and one-half tons, has a total energy of over 2,700 foot tons, with twelve inches penetration of wrought iron, whilst the 12 inch, weighing 45 tons, develops an energy of 26,000 tons, and has a penetration of 27 inches of wrought iron.

The first steel gun made for the navy was of 6-inch caliber. The tube was of domestic steel, but the jacket was English. The second gun of the same caliber, now on board the "Dolphin," is wholly of domestic steel. The original requirements were: T. S. 70,000 lbs.; elastic limit 26,000 lbs.; elongation 20 per cent; reduction 35 per cent. We now require from the oil-tempered material

	T. S. pounds.	El. L. pounds.	Elong. 2 inches.
Tubes, . . .	70,000 to 80,000	83,000 to 88,000	12 to 22 per cent.
Jackets, . . .	74,000 to 85,000	34,000 to 40,000	12 to 20 "
Hoops, . . .	90,000 to 100,000	45,000 to 50,000	12 to 18 "
Trun. Bands,	80,000 to 90,000	86,000 to 40,000	6 to 12 "

Test specimens are cut transversely as well as longitudinally. "Forgings must be made of open-hearth steel of domestic manufacture, from the best quality of raw material, uniform in quality throughout the mass of each forging, and throughout the whole order for forgings of the same caliber, and free from slag, seams, cracks, cavities, flaws, blow-holes, unsoundness, foreign substances, and all other defects affecting their resistance and value."

The trunnion band is an unhammered steel casting, rough bored and turned, annealed, oil-tempered, and again annealed. It is screwed on and held by a set screw. The elevating band of wrought iron is shrunk on and keyed. All other parts of the gun proper are forged steel. The steel maker is required to discard 30 per cent of the top and 5 per cent of the bottom of each ingot. Tubes, jackets, and hoops are forged from solid ingots and afterward bored. For tubes we require the bored ingot to be reduced 50 per cent in thickness, and for plugs and mushrooms the same. Jackets must be reduced 33 per cent, and hoops at least 30 per cent. All forgings, after forging is completed, must be annealed, oil-tempered, and re-annealed. Tubes, jackets, and hoops are forged closely to dimensions and afterward bored.

Without entering into the details of gun construction it will suffice to state that over the tube is shrunk a heavy jacket, about one-third the length of the tube. From this jacket to the muzzle are shrunk a series of lighter hoops. Outside the jacket are again shrunk a row of heavy hoops constituting a second reinforce over the powder chamber and the seat of the projectile. The breech-loading apparatus, of the interrupted screw type, locks into the rear end of the jacket.

By the method of shrinkage, the bore in all the new guns is compressed nearly to its elastic limit, i. e., about 35,000 lbs. The actual diametrical compression rising from 0.005" at the muzzle to 0.016" at the rear end of tube.

All calibers have about the same strength, though the larger have a greater factor of safety than the smaller ones. Slower burn-

ing powder is used in large calibers. Were it not for the erosion of the bore by the gasses of explosion the life of these guns would be indefinitely great. Raising steel to a strain closely approximating its elastic limit raises the limit itself, and if this could go on, the strength of the gun would be infinitely great.

The erosion mentioned causes unevenness in the bore, and this in turn affects accuracy. A new steel liner corrects this evil. Five hundred rounds would probably injure a large gun so as to necessitate relining. One of the "Dolphin's" 6-inch guns has been fired over 300 rounds with little apparent wear. Abroad, 10 and 12-inch calibers have been fired from 600 to 800 rounds without relining. Target charges are reduced, and the velocity falls to 1,700 f. s. in place of 2,100 f. s. The maximum pressure now allowed in the bore is 15 tons, say 32,000 lbs. per square inch, but we anticipate pressures as high as 17 tons in the near future. The muzzle pressure is about 4 tons.

The cost of these guns, roughly speaking, is about 50 cents per pound when ready for service. The price per pound falls with increase of weight.

Although a 16-inch gun to weigh 125 tons has been authorized by Congress and designed, it is more than doubtful whether it will ever be constructed. Possibly a 13-inch caliber, weighing about 60 tons, may be substituted. The recent failures of English 100-ton guns has cast discredit upon monster ordnance, and as a 13-inch gun can penetrate 28 inches of wrought iron, there is little to gain in exceeding this size. Ranges of modern high-powered ordnances are above one mile for each inch of caliber at extreme elevations. The length of the gun is a more important factor than the size in this respect.

The largest guns in the world were made by Krupp for the Italian government. Weight, 119 tons; caliber, 15.7"; length, 46 ft.; weight of projectile, 2,028 lbs.; charge, 727 lbs., though 860 lbs. has been fired; velocity at muzzle, 1,800 f. s.; energy, 46,000 foot tons; penetration, 30".

STEEL CAST GUNS.—Under act of Congress, two 6-inch steel cast guns, weighing about $5\frac{1}{2}$ tons each, have been offered for statutory trials. The first trial was of Bessemer steel. About 20,000 lbs. of metal were poured, the gun being cast solid. After rough boring, the gun was first annealed, then steam-tempered and again annealed. The

rifling was done at the Washington navy yard, and the gun taken to Annapolis for trial. The conditions imposed ten rounds in quick succession, and the charge sufficient to ensure a muzzle velocity of 2,000 feet per second for a 100-pound projectile. A preliminary warning charge having been fired, the gun was loaded with forty-eight pounds of brown prismatic powder and projectile. The gun went to pieces abaft the trunnions, the bursted segments completely wrecking the heavy 12-inch timbers built over and around it. The breech mechanism was found intact. The pressure gauge indicated fourteen tons. As the usual energy of such a charge is fifteen tons, it is evident that the walls of the gun gave way before the gasses had been fully evolved. The physical characteristics of the metal were:—

	T. S. lbs.	El. L. lbs.	Elong. in 2 in.
Breech long., . . .	89,686	51,693	9.75 per cent.
“ trans., . . .	73,236	57,290	0.60 “
Muzzle long., . . .	81,185	40,461	18.00 “
“ trans., . . .	79,174	41,500	16.50 “

The wide variations and almost total absence of elongation in the transverse breech specimen are full of significance. As the gun was cast breech up of indifferent metal, with an utterly insufficient sinking head, the reason for the unsatisfactory breech specimen appears. A chemical analysis of the borings constituted as good an instance of lack of homogeneity and marked segregation as exists. The failure of this gun shows that poor steel, badly treated, cast without safeguards, tempered by a process as unusual to good metal as to the maker, will not bear strains that call upon the best steels for all their elasticity and strength.

The second gun was of open-hearth steel, of good metal, cast by a company of acknowledged merit, with every precaution their large experience could suggest. This gun withstood the ten rounds without apparent injury, but the star gauge developed serious enlargement of the bore. The elastic limit had been exceeded, and the gun ruined for ordnance purposes. In Sweden, however, guns up to 5.2-inch caliber have been successfully cast and successfully fired. It is useless to go over the arguments of built-up versus steel cast guns. Certainly, the advocates of the built-up guns have the best of the facts. I hazard little, however, in believing that the question may assume a different

aspect with the improvement in casting. The present system has in its favor the practical impossibility of incorporating bad steel in any gun. The navy is fully committed to the built-up system, and the guns we are now building are in all respects the equals, and in many the superiors, of those of any other nation.

STEEL GUN CARRIAGES.—The pneumatic gun carriage has every part of steel. The slides are horizontal, and the downward strain is taken entirely from the deck (excepting the component due to impact). The strain from the recoil is taken up in line with the horizontal side cheeks, by means of recoil cylinders supplied with compressed air from a reservoir and air compressor. The pistons are solid, without packing, and less in diameter than the cylinders. This permits a displacement of air in recoiling, giving nearly an equilibrium of pressures at the termination of the recoil. The difference in areas of piston head and back is sufficient to bring the gun back into battery. The initial cylinder pressures are from 250 to 400 lbs. per square inch. The mean pressure during recoil is slightly over 700 lbs., and the maximum pressure about 1,900 lbs. The usual length of recoil is less than 24 inches, but the length can be reduced. The carriage is trained and the gun elevated by one man standing at the rear. The extreme elevation is 18° , depression, 5° . The gun is also loaded by pneumatic power. This carriage has been successfully tried, and one of our monitors is now being equipped with them. The one serious difficulty yet encountered with it is the leakage from the recoil cylinders. Though not accepted as a navy standard carriage, it has been tested and adopted for special use.

In thus reviewing the steps by which steel has supplanted iron for naval purposes, I have deemed it essential to dwell at length upon the rigid inspection and tests exacted prior to acceptance of material. Naval inspection has served to establish standards where none previously existed, and its influence upon the character of steels throughout the whole country has been marked and salutary. It is not an exaggeration to add that the navy demand, though not exceeding one per cent of the total product, has served to raise the character of steel in every art. Beyond this, the encouragement afforded by government orders, has rendered possible the installation of special plants requiring enormous capital. Once established, the entire country reaps the benefit of the improved manufacture. The possession of efficient men-

of-war, armed with powerful guns, capable of sustaining the dignity of a great power, is the least of the advantages reaped by the nation. The direct service to every mechanical trade has already returned to the people the prime cost of the new navy.

MEETING 401.

The Application of Storage Batteries to Street Car Propulsion.

BY COL. E. H. HEWINS.

The 401st meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, March 27th, at 8 P. M., President Walker in the chair.

After the reading of the records of the previous meeting, and the election of new members, the President introduced Col. E. H. Hewins, general manager of the Union Electric Car Company, who read a paper on "The Application of Storage Batteries to Street Car Propulsion."

COL. HEWINS said: The question of street transportation is one that more nearly concerns every individual in the community than almost any other, and its solution is one that has occupied prominently the attention of engineers in all ages. The modern horse car is the result of the accumulated experience of ages, but now the demand is for something still better. In this service is invested immense capital, it furnishes employment to thousands, it serves millions, and comes into most direct contact with the masses.

Here is the opportunity, and perhaps here more than anywhere else is to be wrought out the old problem of the proper relationship between capital and labor, and state or corporate ownership. The signs of the times already indicate this latter to such an extent that all should take note of passing events, and the Nationalist says the community must address itself to the solution of this momentous question.



In many cities the streets have become so encumbered with horse cars that it is absolutely necessary to find some improved means of meeting the rapidly increasing demand, and here as in New York it would seem that an elevated road must soon come, that no improvement now contemplated or dreamed of in surface facilities could possibly keep pace with what sometimes seems to me an insatiable and growing desire to ride,—so great is the increase wherever the opportunity is furnished.

It has always seemed to me that the matter of street traffic was similar to building uses. When you settle a new country, you first build log huts with one or more rooms on the ground. As the country fills up, and houses get nearer together, you put first attics and then more stories to the buildings,—the more people and business the higher the structures. Now the Government undertakes to supply the road or street facilities for communication; but, not as enterprising as individuals, provides but one story. Let me ask why should we not, in congested districts, have two-story streets as well as high buildings?

It is not my purpose to quote statistics or to recite history, but to give some explanation of one method by which it is hoped to improve our street car service, and to that end the application of storage batteries to street car propulsion ought to be both interesting and instructive. It is unnecessary to relate the desirability, for many reasons, of avoiding the net work of wires employed by the trolley system, nor the numerous advantages of having each car complete in itself, self-contained, and able to travel wherever there may be tracks without other special constructions or obstructions. These are all unquestioned by any of whatever belief or interest. It resolves itself into the one dispute as to whether the thing can be done

The experience of most of those who have tried it is pointed to as disastrous on the ground that storage batteries cannot endure, and it is said that when storage batteries have been so far improved that they can be depended upon to deliver the necessary power, then we may have the ideal motive power for street car service.

There is one peculiarity that is common both to the storage battery and the dynamo,—they may be likened to the thoroughbred, who will do all that is asked of him, though he die in the attempt. If used within his capacity, a most serviceable animal, but if thought-

lessly, carelessly, or ignorantly used, a very costly horse may be quickly and seriously injured. So far as I have been able to learn, with one exception, the employment of storage batteries for street-car work has thus far required a drain greater by far than any maker ever claimed to be their ability to deliver. The result has been the prompt destruction of the battery.

It may be well to interject here some of the characteristics of storage batteries, though not with any purpose to undertake a thorough description of this peculiar agent. I gather from the different details of construction shown by different makers that in one respect they may be separated into two classes,—one constructed upon the theory that as much *surface* of plate as possible should be exposed to the solution, and the opposite that *mass* of active material is the desired object.

Your attention is directed to the several elements shown on the table, which illustrate these two extremes to a great degree, as well as other characteristics. In one you will observe that the plates are thin and placed near together with as many plates as possible, giving large surface in contact with the solution in which the plates are immersed; while the other is constructed of thick plates placed far apart, thus exposing comparatively small surface to the solution, but containing large mass and large surface between the active material and its carrying lead plates, which is claimed to be desirable. Again, we see a pile constructed upon quite a different principle. Its active material is not made in the form of a paste, paint, cement, or powder; but is melted and cast, so that it exposes more surface to the solution than either, and is claimed not to deposit or waste away in use.

I also understand that the nearer together the plates can be put without touching the better, provided they can be secure of parallelism. In two of the piles here shown is a marked peculiarity to which I would call your attention, *i. e.*, the one that is mechanically the most certain of remaining in position has double the space between its plates that is exhibited in its competitor.

However it may be obtained, whether by small space between the plates, by large amount of surface exposed to solution, by large mass of active material, or by large surface contact between active material and its carrying lead plates,—the desired objects to be secured are low internal resistance and capacity.

As throughout the realm of physical science there is no gain without compensation, so each of these various qualities is obtained only at the sacrifice of some other. (Later on I shall call your attention to a seeming contradiction of this theory where we "eat our cake and save it, too.") Just what relative proportion in these various respects will in the aggregate give the best results will probably never be agreed upon by the different competitors. The purchaser, whether competent or not, must decide for himself.

In the practical use of storage batteries it is desirable to charge and discharge at a low rate. If the rate be too high, the heat generated expands and warps the plates. The expansion, or rather the subsequent contraction, injures the contact between the active material and lead; the warping brings adjacent plates nearer together at places; both resulting in the generation of more heat,—one because of imperfect contact, and the other because of the greater flow of current at those places where warping has taken place; and so the work of disintegration goes on with increasing rapidity. If, however, the rate is confined within certain limits, it is found by experience that the batteries endure, except for the slow, gradual wasting away of active material in a powder form from the positive plates. This is not expensive in its renewal, but the effort now is to reduce the rate of this reduction.

The question then comes: How to do the service with less, or, what is the same in effect, how to economize the energy we have at command so as to keep within the capacity of the battery. It was conceived some four years ago by Mr. William L. Stevens, then and now electrician for the N. E. Weston Electric Light Company, that the gearing employed to transmit the power and to reduce the rotative speed from the motor armature to the car axle, exposed as they were to dust and not well lubricated, must be a very inefficient method of transmission, and his studies and experiments finally produced a train of gears which, instead of the exposed gearing in common use with counter-shaft passing through between the field coils, is nested concentrically around the axle, enclosed in a dust-tight case, and runs in a bath of oil. In addition, the strains in all but one place are equalized on opposite sides of the shafts, so that the minimum of friction and wear is secured. Careful measurements have shown that not less than one-half the electrical energy is consumed in the friction of the

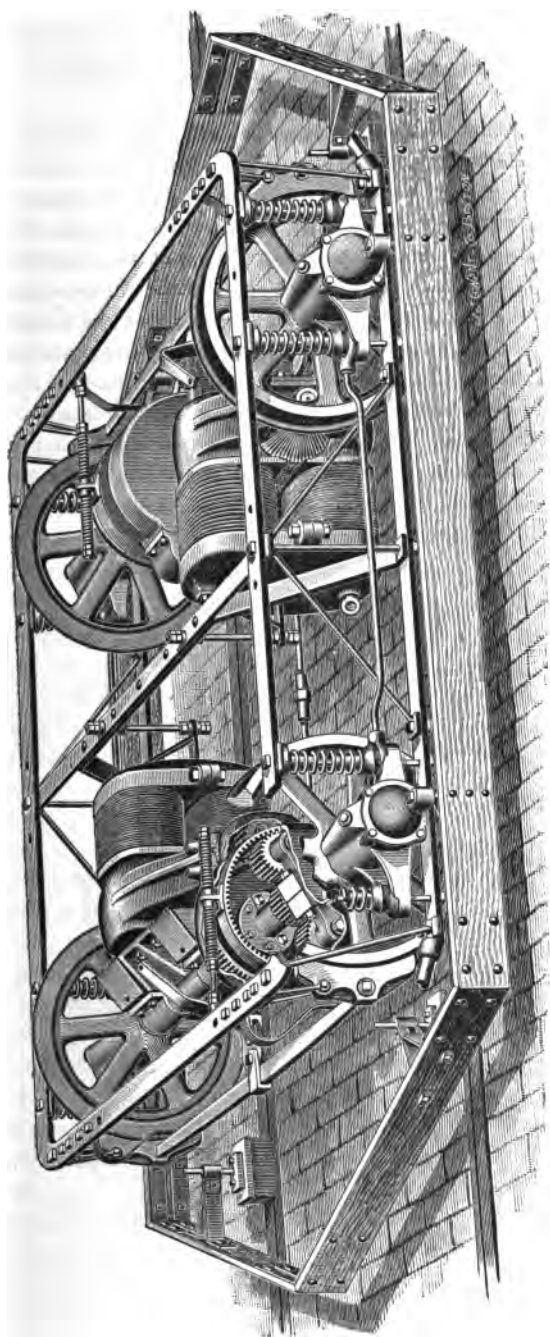


Fig. 1.

exposed gears and bearings in common use. This friction is made manifest by the wear, practical examples of which are exhibited upon the table. Here are four pinions from one of the prominent systems, worn out as you may see, one in less than one month, the average life said by the road officials to be about two months. In contradiction, here is the pinion from an armature shaft of the Stevens gearing that has run about 8000 miles, and you can see that it has lost practically none of its life. Thorough lubrication and cleanliness are the secrets of its endurance. You will also notice the difference in the faces of these pinions,—the one that shows little or no wear has but $2\frac{1}{4}$ " face, while the others have $4\frac{1}{4}$ " face. The one has not been required to transmit more than one-half the power of the others to accomplish the propelling of the car. Fig. 2 shows a pinion made of cast steel which was worn out in four months' use.

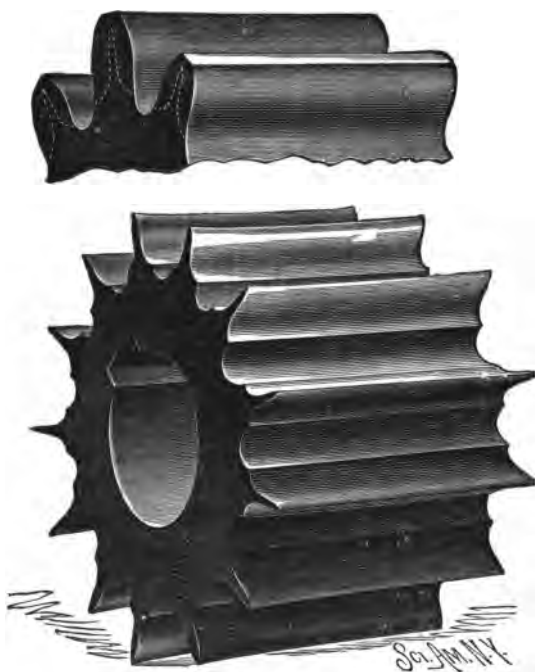


Fig. 2.

In addition to the saving of energy and repair is the fact that the truck rides much easier, not being rendered stiff by the gearing and counter-shaft,—quite a difference in the agreeable riding of the car, and also, what is more important, an absence of noise from the gears, which, when considerably worn in the systems with which you are familiar, is very excessive; so that conversation is difficult. No doubt many of you have noticed that when new cars or lines are started the noise is very much less than after being run a few months. This is very largely due to the wearing of the gears.

Another important feature of Mr. Stevens's invention is called the "recharging" device. This invention consists in rendering a series-wound machine, either a motor or dynamo, as the occasion may call for, without the necessity of human intelligence or action. The possibility of doing this without mechanically reversing the field connections, and the application for a patent, were denied, and it required quite an effort to convince the Patent Office that it was being done daily. It simply consists of a few cells of battery put into a shunt circuit with the field coils. The result without these supplementary cells is that when the car tends to run faster than the position of the switch handle indicates is desired, the counter e. m. f. becoming equal to that at the binding posts, no current flows, and consequently there is no magnetization of the field magnets; but with the elementary cells the field is kept charged in the right direction, and immediately the speed has increased beyond the desired rate, the machine driven by the car generates a current in the direction opposite to that which drives it as a motor, and the current so generated is returned to the batteries or to the line as the case may be,—for it is to be understood that this system is equally applicable to storage battery, to overhead or underground conductors, or to a combination of the two. For instance, there are places where overhead construction might be unobjectionable and even desirable, but on a continuation of the same route inadmissible. In such cases the car would habitually be started with current from the battery, and after having attained a proper speed be switched onto the trolley, and while so connected the battery would be charged. When the end of the trolley wire is reached, the car would be run over the balance of the route entirely with current from the battery until its return to the trolley wires.

Cars equipped with this system are habitually run down hill, and

restrained from going too fast and stopped by this recharging device, the hand-brake being used only when stopping on a grade, and to hold the car while standing. Thus it will be seen that the energy of the ordinary brake employed by other systems to hold the car from going faster than desired, or to stop the car, is by this system returned to the battery to be used over again, or to the line to reduce the amount of power generated in the power house. This is saving the cake that is also eaten. The amount of energy so returned to the batteries on the Beverly and Danvers street railway is determined by careful measurement to be about fourteen per cent of that taken out, and after reduction for efficiency of batteries, loss in conductors, etc., leaves about nine or ten per cent, as the increased mileage due to the charging back device. The motion of the car is by its use made much more agreeable, and its control more effective.

Had the car that recently ran into another on Warren Street been fitted with this simple recharging attachment, the collision would not have taken place, notwithstanding the fact that the trolley was off the wire.

The two curves shown in Figs. 3 and 4, taken on different electric railroads, showing in a graphic method the amount of horse-power necessary to propel electric cars, are interesting. The curve in Fig. 3 was made from data taken on a car on a level road, using the ordinary overhead single trolley system, with the motor armature geared to the wheels by the ordinary two sets of gears open to the dust gathered from the road. The curve in Fig. 4 was formed from data taken on the Beverly and Danvers Railroad, which is very hilly, on a car equipped with this system. As will be seen from the first curve, it took about twelve horse-power to start the car at first, the gear being new; and at a certain part of the road consumed 20.1 horse-power. The next start took 21.4 horse-power, while the third start took 33.5 horse-power, presumably owing to the gear getting dirty, making an average throughout of 9.8 horse-power over the whole run. In the lower curve on the Beverly road the car was started with from 5 to 10 horse-power, and running at the same speed as in the former test the highest horse-power consumed was 16.1, while, where the curve passes below the horizontal or "no-current" line, considerable saving was effected by charging back, as much as 19.8 in one case being returned to the battery. The average horse-power in this case



Fig. 3.

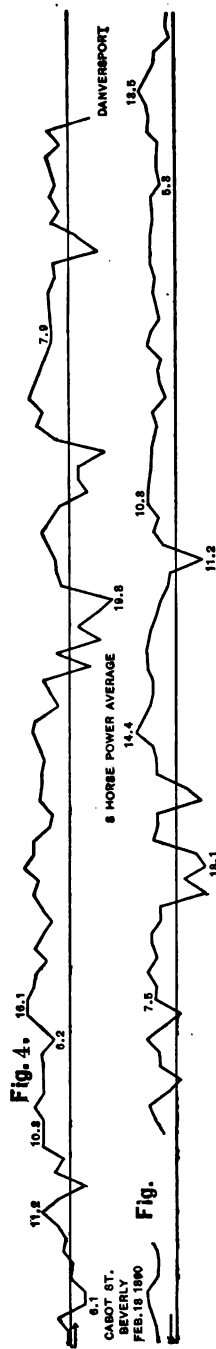


Fig. 4.

Figs. 3 and 4.

is put down at 6, but as a matter of fact it is about 5.54. The saving over the whole line by charging back is about fourteen per cent, as stated above. The saving in such a case is not at first easily seen, but we think a careful study of the above curves will prove that there is yet much to be improved in the ordinary method of running electric cars, and they will serve as an explanation of the acknowledged and unnecessarily high power which today is regularly being consumed on electric railroads.

The methods that I have tried to describe to you perhaps seem too simple and too easy of accomplishment to be sufficiently effective, but a serious attempt to do it I think will convince the most sceptical that it is not so easy as one would be inclined off-hand to assert, and it is a fact that a sufficient amount of power is saved to enable the storage battery in its present stage of development to do the work. This is the important consideration, and what it has been sought to accomplish. I do not doubt that the frequent recharging of the batteries while in service increases their endurance, and no doubt the constant agitation of the solution enables them to withstand heavier drains than would be the case with stationary work.

This system was applied last summer as the motive power to a transfer table at the car shops of the Fitchburg Railroad at East Fitchburg. The current is taken from the same dynamo that furnishes light for the shops, and is carried to and from the motor by two wires and trolleys.

MEETING 402.

Experiments with Alternating Currents.

BY PROF. ELIHU THOMSON.

The 402nd meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, April 10th, at 8 P.M., Prof. C. R. Cross in the chair.

After the reading of the records of the previous meeting, the chairman introduced Prof. Elihu Thomson, of Lynn, who read a paper on "Experiments with Alternating Currents."

PROF. THOMSON said: The study of alternating currents and the effects of such currents in producing fields of magnetic influence has been greatly stimulated by the industrial development taking place with alternating currents in electric lighting. In particular, the phenomena occurring as a result of induction and self-induction have opened to us very many interesting fields for study and investigation. The consideration of the action of displacement of phase due to induction or self-induction, as the result of a retardation or lag brought about by such induction or self-induction, has been particularly interesting and fruitful. Much light has been thrown upon the more obscure actions occurring in ordinary electrical apparatus using continuous currents by the analogous but more pronounced effects obtained with alternating currents. The subject of losses due to magnetic friction or hysteresis has been and is receiving careful study in the hands of some of the ablest electricians. The revival of the almost forgotten idea that the static spark or Leyden jar discharge is an alternating discharge at a very high rate or speed of reversals has not only assisted in our general understanding of electrical actions, but has borne fruit, it may be truly said, in the experiments proving that light and radiation are phases of electrical action,—not, as I have seen seriously discussed that light and electricity are one and the same thing, but that light and radiant heat are related to the science of electrical undulations or vibrations. It becomes simply, then, a widening of the electrical field to cover light and radiation, not a question of identity in all respects.

In the same way I anticipate eventually that we may learn by experimental research, coupled with theoretical considerations, that conduction of electrical current is not different from electrolysis in essence, except that the interchange of atoms in molecules of the conductor replaces that occurring in the electrolyte, and where the conductor is a solid a restriction of the decomposing and reforming molecules to definite positions occurs, while in the electrolyte the newly formed molecules are freer to move, and may therefore take new positions.

I anticipate, further, that we may learn that the warming of a body absorbing light or radiant energy is a result of almost infinitesimal closed electric circuits, just as the warming of a copper plate exposed to magnetic waves is due to electric currents on a larger scale. It may be possible also that we may learn to regard atomic move-

ments, or transfers of atoms from molecules to other molecules in chemical actions, as brought about by electrical strains; perhaps to find that the dispersion of light by refracting media is in reality closely related to such strains affecting the atoms or atomic structure, as distinguished from the molecular structure; or it is a kind of atomic interference phenomenon. Already we are compelled to admit that the atomic structure of heated gases is such as to enable the atoms to give out definitely repeated electric strains, that is, definite wave lengths of light or color,—that the atoms are, as it were, like tuning forks of definite pitch, which, instead of setting up sound waves, can give forth electric waves.

It is not impossible that the science of chemistry itself may be adjudged to be a department of electricity. Whether gravitation and other molecular forces and properties will eventually be found to be so closely related to electrical actions is difficult to say. Perhaps we may be able to make the broader statement that the properties of the universal ether are electrical, and all the phenomena of the physical universe are closely related to, or exemplify the properties of, the ether.

I have extended this opening statement to some length, chiefly because I did not wish to miss the opportunity of furnishing, if possible, some food for thought, and because what we are to deal with in our experiments here are some instances of phenomena which depend directly on the ether motions, and not on the air, that is, they depend upon waves in the ether differing from those of light and radiation by being of extremely slow rate comparatively; but a very few hundred a second instead of millions of millions.

If we pass an alternating current through a coil of wire surrounding an iron wire core, or even if such core be absent, we will obtain an alternating magnetic field around the coil and core. The polarity or direction of the magnetic lines in such field is reversing a number of times per second, equal to the number of changes in the direction of the current in the coil. Now, if we immerse in such field in the proper way a closed coil of wire, a band of conducting metal, a plate of metal, or in fact any substance which conducts electricity, it will be the seat of currents of alternating direction corresponding to the inducing currents in the coil. The coil, band, or plate becomes a secondary circuit for the inducing coil. The ether waves or magnetic waves produce

waves of current in the conductor. There is, however, a strong repulsive effort exerted upon the closed coil, band, etc., when it is of such size and material as to have the currents induced subject to great self-induction. If the currents induced lag or are retarded, they become opposite in direction to those which produce them, instead of alternately opposite, and in the same direction. The currents induced tend to maintain a magnetic field of opposite direction of polarity to that of the inducing currents or field at any instant. If the closed coil or secondary band exerts by the currents induced in it a controlling effect upon the magnetic field, such that the normal directions of the magnetic lines set up around the inducing coil are greatly distorted, the repulsive effect is strongly produced, and can forcibly thrust the ring or band away from the coil, or it may balance the ring for a moment in free air (Fig. 1). Could we obtain a condition of stable

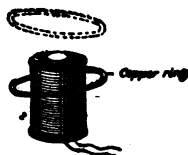


FIG. 1.



FIG. 2.



FIG. 3.

equilibrium in this case the ring would remain suspended, but the condition is one of unstable equilibrium, and the ring or band can only float securely above the coil when stayed at one side by horizontal strings.

Plates and discs of copper are likewise repelled or sustained. When one ring of copper is held in suspension above the coil or pole by alternating currents, another ring may be added and is supported closely parallel to the first ring, in virtue of the agreement of direction of the induced currents in both rings, which causes attraction, or makes them act as one ring. Too heavy a mass of copper, such as a heavy copper plate, will, however, cut off or so far distort or reflect the magnetic lines as to nullify their effects on a ring placed above the plate. This is exemplified very easily by substituting for the ring a

coil of insulated wire, whose terminals are carried to an incandescent lamp (Fig. 2). The lamp is lighted when the lamp-coil is held near the inducing coil or pole, and extinguished when the heavy induction shield or plate of copper is inserted between them. Hence, to cut off induction from reaching an object we may enclose it in a heavy copper box or shell, in about the same way as we cut off or shield an object from magnetism by enclosing it in a heavy iron box.

The lamp experiment just described suggests another, in which the lamp and the coil, for giving current to it, are floated, or rather immersed, in a vessel of water as in a jar, and then placed over the alternating pole (Fig. 3). Not only does the lamp light in the water, but the lamp and coil are lifted or supported from sinking, and at a depth depending on the current in the inducing coil, or the strength of the alternating field which it engenders. The lamp is self-regulating for variations in the force of the prime source of current. By counterpoising the lamp feeding-coil on a lever (Fig. 4), the brilliancy of the

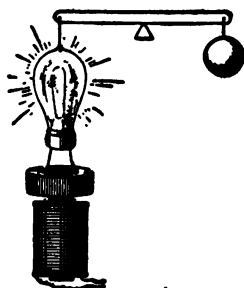


FIG. 4.



FIG. 5.

lamp may in like manner be set by suitably weighting the lever. Or if several lamps in series be used, connected flexibly to a coil in the magnetic field of another coil, and either the primary or the secondary coil be balanced so as to tend towards the other with a definite force, the regulation of brilliancy is preserved not only during changes in the force of the primary current, but also during changes in the number of lamps in the series lighted by the coil. In other words, we are able to secure a complete regulation for all conditions. The device is an alternating current transformer, yielding a definite current strength for the operation of arc lamps, incandescent lamps, or other devices, either singly or in series of two or more. The lamps are

provided with the usual shunting switches. I have found also that the regulation may be obtained by governing in a similar manner the reaction or self-induction of the primary itself, or the primary current may be caused to traverse a series of lamps and a reactive coil, and the secondary coil or band be simply a partially balanced closed circuit, movable automatically to change the self-induction of the reactive coil, of which it is the secondary. It will be seen, then, that the repulsive action can be used practically in regulation of alternating current. Very good and effective practical measuring instruments, as well as alternating motors, have been based on the same principles of obtaining movement from such currents. Our time does not here permit a description of these. The regulating mechanism of arc lamps for alternating currents can equally well embody the repulsive devices of the closed band or circuit, and a coil in circuit with or in shunt to the arc.

We have shown the experiment of causing two rings to be attracted and held together while subjected to the alternating field. If we substitute for one of them a disc of copper (Fig. 5) pivoted so as to rotate easily, or a disc of iron likewise pivoted, we can, on variously placing the closed ring and disc in the field, obtain brisk rotation of the disc. A plate of copper or brass may be substituted for the ring, and, in fact, any closed conducting plate or piece of metal may be used. The action is due to the formation of parallel currents, or harmonizing and attracting fields, where two copper pieces are used, and to retention of magnetism or hysteresis where one of them is of iron.

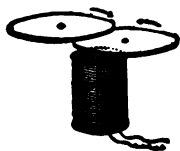


FIG. 6.

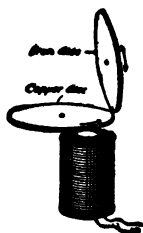


FIG. 7.

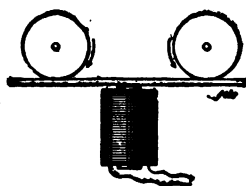


FIG. 8.

I would say here that Mr. M. J. Wightman and myself have carried on these experiments to a considerable extent, and amplified their effects in many ways, constructing motors, regulators, etc. based

thereon, and that they are capable of very much extension and modification. Some experiments of a novel character were shown last year at the Paris Exposition, and were based on the principles just touched upon. I have since that time extended the list, and now it includes quite a large number of curious devices.

In the disc experiments shown we used one disc and a shading plate or circuit, held stationary. By employing two discs of copper, (Fig. 6) or of copper and iron (Fig. 7), it will be seen that both may revolve, as one serves to modify the field for the other in each case. The positions of the discs relatively to the field are found capable of being considerably varied, and the rotative actions are readily made to take place in one or other direction. These variations are easily found by trial.

The discs of iron or copper may also be set rotating by a core wound with a coil conveying alternating impulses, and surrounded by coils or circuits which can be closed at will. An unsymmetrical placing of the disc, and an unsymmetrical position for the closed circuit, with reference to the middle of the length of the core, is conducive to this effect.

A curious variation of the rotating disc effects is obtained with pieces or bars of hard steel or iron, which resist reversal of magnetism. Placing a bar of steel, such as a file, upon the alternating pole, and holding the discs near the file (Fig. 8), is attended with rotation of the discs in a direction indicating a magnetic flow, or shifting set of lines or magnetic poles, proceeding along the file, from the vicinity of the alternating or inducing pole. Two or more discs may be easily set moving by the file laid across the pole. It will be noticed that while the copper discs operate only when their plane intersects, the direction of magnetism or magnetic lines leaving the pole, the iron discs operate in any position with respect thereto. This is easily explained by the fact that the copper discs move by virtue of *currents* set up in them by the changes in the magnetic field, and particularly in obedience to the shifting of the field, while the effect on the iron disc is almost purely magnetic, and not dependent on induced currents set up in it. The tendency to resist change of magnetic state accounts for the fact that the edge of the iron disc follows or tends to follow the development of polarity in the steel, which also resists magnetic change, and which therefore changes only progressively.

A curious experiment, combining the effects of closed circuits around cores and hysteresis, or resistance to magnetic change, is seen in the use of a cast-iron ring, on one part of which is wound a small coil of copper wire, closed on itself. When this is laid down so that the part of the ring near the closed coil rests on the alternating pole, and the pivoted iron disc is held near the center of the ring with its plane parallel to that of the cast-iron ring, there is noticed a rotation of the disc in a direction coinciding with propagation of magnetism around the ring, from the inducing pole along that side of the ring on which the closed coil is not wound, said coil appearing to shield or cut off its propagation in the other direction around the ring. The currents developed in the closed coil beat back the magnetic lines, while they remain free to move along the uncovered portion of the iron ring, and so drag the disc around also.

By taking advantage of the principles set down we may construct a simple motor, such as is here seen. A ring of laminated iron has a slot cut through at one part. The rest of the ring is wound with insulated wire through which an alternating current may be sent (Fig. 9). The sides of the slot or pole faces are partly shaded or

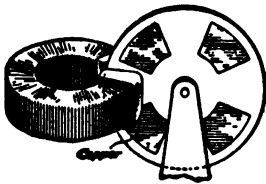


FIG. 9.



FIG. 10.

shielded by copper circuits affixed thereto on the upper part. The effect of this is to retard the development and change of polarities in the upper part of the opposed pole faces, and leave the action unhindered in the lower part.

Placing a copper disc mounted so as to be easily rotated, with one part of its edge in the slot, there results a vigorous rotation of the disc and the exertion of some torque. Removing the disc, we may

use the slot as a coin detector, for a silver coin is drawn in at the under side and projected upwards with vigor, while a base metal coin is not so affected, the superior conductivity of the silver for the current induced in it deciding the question (Fig. 10).

We may also cause rotation of a copper disc by holding it flat-wise over the alternating pole and then placing a core of iron wires above the disc, but offset laterally from the axis of the alternating pole. The disc is immediately set into brisk rotation.

Copper balls or cylinders may be substituted for the discs. With a hollow copper ball resting on a shading plate (Fig. 11) placed over the alternating pole, curious rotatory effects are readily produced. Similar effects are produced when the balls are immersed in a vase of water over the pole (Fig. 12), the pole being partly covered by a copper or brass plate. The copper ball will even rotate on a horizontal axis, while resting against stops and on a copper shading plate, a movement showing considerable vigor of rotation which even overcomes the equatorial friction of the ball on the plate.

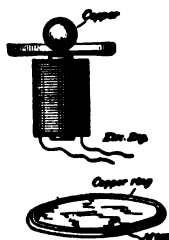


FIG. 11.

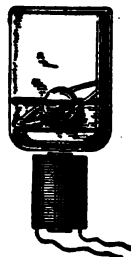


FIG. 12.

Here, as before, the cause of the action is the moving magnetic field in which the ball is immersed. The effects are those of retarded development of magnetism over the shading plate as compared with its development over the free part of the pole. This virtually amounts to a shifting of bundles of magnetic lines from the free part of the pole towards the shaded part at every alternation of current. These bundles may be said to brush the balls around. A copper cup may take the place of the ball in some of these experiments, or both ball and cup may be used together, while curious effects are obtainable from them.

A very good device for supplanting the copper and iron discs in some of the experiments is a combination of the two. A small shaft has some thin iron washers strung on it at the center, and around the edge of the iron discs is placed a copper ring or band, forming an overhanging rim like a pulley rim. The shaft is hung in a suitable frame to allow the device to be handled.

Placing a wedge-shaped piece of iron on the alternating pole, and with its edge upward (Fig. 13), we may bring the induction wheel, just described, near the edge, but to one side of it, and we will obtain brisk rotation of the wheel. On the other side of the edge the rotation is reversed. The action is due to the same cause as was found

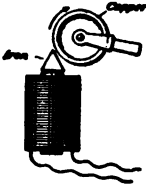


Fig. 13.

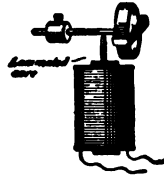


Fig. 14.

in the case of the steel file, though it is a curious modification, inasmuch as the appearance is as though something passed off the edge of the wedge, and blew the wheel around.

I have reserved for the last instance of these actions the case of a gyroscope of novel construction (Fig. 14). The wheel is like that just described, but it is mounted on pivots borne in a copper frame surrounding the induction wheel, which frame is in turn provided with a bar for pivoting and for a counter-balance weight. The instrument thus constituted is hung on a pivot placed in the center of the alternating magnet pole and held for a few moments, during which the wheel gets into rapid rotation. It is then capable of exhibiting all the well-known gyroscopic actions, which are a stumbling block to beginners in the study of physics, and than which nothing could be more simple and easy of comprehension when the true meaning of the actions is grasped. It is, indeed, curious to notice that in this electric gyroscope we have the electric rotations obtained, no doubt, from a direct absorption of ether energy or wave motion, without connection, electrical or mechanical, and that they are obtained altogether inde-

pendently of the gyroscopic rotations, which latter are not interfered with by the electric action.

The discussion of each case of movement produced in the experiments has necessarily been of the briefest kind, but it will be understood that there is material for minute study in any of the cases which have been shown. Many of the effects can be indefinitely modified. The examples given are intended to show in what respect the properties of an alternating field are such as distinguish it sharply from the ordinary unreversed field of a magnet, subject to the action of continuous current only. The experiments also bring out forcibly the effects of lag with alternating current waves. It is needless to say that the whole action and theory of lag or retarded phase has nothing parallel in continuous current work; that in dealing with alternating electric currents it is a most important action or effect, and that without a due regard for its importance many of the most interesting and instructive phenomena of alternating currents will fail of being correctly understood.

The paper was illustrated by numerous experiments and black-board diagrams.

MEETING 403.

Central Electric Light Stations of London.

BY MR. FRANK M. GILLEY.

The 403rd meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, April 25th, at 8 P. M., Hon. Jacob A. Dresser in the chair.

After the reading of the records and the transaction of some business the chairman introduced Mr. Frank M. Gilley, of Chelsea, who read a paper on "Central Electric Light Stations of London."

Mr. GILLEY said: Electric lighting in London does not have a long history, and if measured by what has already been finished would

not excite even passing notice. But it is the "what may be" successful systems that are now on trial there which the whole scientific world studies with interest. Activity in the promotion of companies to supply electric lights is of comparatively recent date, and it is only within the past year that the public has sought electric light stocks for conservative and legitimate investment.

Great Britain far surpasses us in legislation and red tape. In 1882 a few central stations were projected, and several cities and towns that were suffering as they thought under the burdens of private corporation gas monopolies were indirectly the cause of the passage of an act by Parliament, whereby electric light stations could be bought by municipalities after 21 years at the assessed valuation of the apparatus. Successful ventures could last 21 years; failures or partial failures would alone remain in the hands of private companies. The municipal control of gas works is common in England, and perhaps as successful as private enterprises but no more so. Private capital did not come forward very freely. Too much legislation had blocked the way, and, with the exception of a few experimental ventures, electric lighting was forgotten. In 1888 the time for the purchase of a plant by the local authorities was extended to 41 years, and some other concessions granted that made electric lighting possible, if not profitable.

To erect overhead wires a "license," i. e., public consent, must be obtained, and of course where buildings are used for structures private consent as well; but as poles in the streets are rapidly excluded, the somewhat expensive and temporary system of housetop circuits did not find favor, except in a few instances, although all companies employing overhead wires exclusively were not subject to the selling out clause in the law of 1882. To obtain the right to open streets and lay underground mains a provisional order must be obtained, and this subjected the company to the danger of being bought at the end of 21 years by the local authorities.

After the change in the law in 1888 there was a boom; systems almost without number had been invented, and some perfected. To try each on a working scale many were ready to supply money, and by the end of last year 179 applications had been sent to the Board of Trade for provisional orders, one-third of which were from local authorities.

The business of manufacturing electric light apparatus is not under the control of a few large companies that use one system and work exclusively under all the patents of some one inventor. Ready made machinery in stock is no more to be found than ready made clothing, and even then the fit is not always to our taste. A variety of systems is made by almost every electrical engineering firm and no two installations look alike. Experimental work is often done in commercial stations, and thus the successful completion somewhat retarded. In striking contrast are the careful laboratory tests of new apparatus in this country, and the ready supply of the same when proved satisfactory.

In England the rights of consumers are carefully guarded, maximum price fixed, dividends in excess of eight per cent allowed if prices are proportionately lowered, and inspection of mains and meters provided for. Here generous concessions are made to companies, subsidies in the form of contracts for street lighting, and land grants in the very streets for poles. Some work in this country has been too hastily done, and the rights of the public have not been carefully preserved. In England current must be furnished at all times to every applicant by meter, and at a price not exceeding a fixed sum.

To a slight extent the low tension two or three wire "Edison system" is in use, but the contest is the most bitter between the storage battery and alternate current systems, the advantage in number of plants being with the latter. In granting "orders" to companies competition has been allowed by the Board of Trade and even favored, especially where both alternating and direct current systems could be supplied in one district, the fact being recognized that the alternate current motor is as yet not a commercial success.

The Metropolitan Electric Supply Company, one of the largest companies in London, has a large area allotted to it, and proposes to erect stations over the entire district of the 1000 volt transformer type with one exception, that of the Whitehall Place Station, which had been in operation some time before it was taken by the newly formed Metropolitan Company.

Whitehall is an imposing building for offices, and faces the Thames embankment and is close to the Grand, Metropole, and Victoria hotels. The building is not fully completed. The station is under the street or place at the rear, is entered through the building, and is connected to its chimney.

The plant consists of three Siemens shunt-wound dynamos, running 350 revolutions per minute, and connected direct to Willans triple-expansion engines, the exhaust steam being condensed in heating the building, passing through two heaters, one warming the water for heating the building, the second for the feed water. Pumps for water supply and elevator are in the engine room, where there is also a large tank for softening water. A fan operated by a steam engine exhausts air into the flue and reduces the temperature 15 degrees, which is 100° at the least calculation. In the Garrick Theatre there are 8 batteries of 44 cells each, charged with only 33 in series, when there are of course 10 sets. The Elwell-Parker type of cells is used here as well as at the station, and furnishes current while the engines are not working from 12.30 M. to 7 A. M. Two 8 sets of batteries, of which one-half are used every other day, can discharge, combined, 1700 amperes. Pilot wires are run to the station from the most distant points of the underground mains about one-half mile away. 100 volt lamps are used except in the theatre. The E. M. F. at the dynamos is 108 volts. Hand regulation is satisfactory with the engines. Three single-ended internally-fired marine boilers supply steam. The roof is formed of iron trusses supporting the paved street above. This station is worthy of notice as deserving a diploma for the hottest engine and dynamo room. It is a wonder that the storage batteries are not injured.

The reason assigned for the apparant want of success with storage batteries in this country, especially in New York and Philadelphia, is, according to English engineers, the excessive heat, but in this room they are operated in an atmosphere at a temperature not far from 100 degrees.

At Rathbone Place, Waterloo Bridge, Manchester Square, 1000 volt alternating stations were under construction. One at Sardinia Street, near Lincoln's Inn Fields, was completed last September. The interior is un-English. There are four 2500 light dynamos driven by compound engines made in this country, and are as much reason for congratulation as any of the notable victories by American scientists and manufacturers. At any rate, American electric lights have been so well liked that the original plant has been more than duplicated. The chimney of this as well as of the Rathbone Place station and many others is built with white enameled or glazed brick on the

outside. Such chimneys can cast shadows only when the bright sun is shining, a rare occurrence in London. At all other times so nearly of the same color and brightness of the sky do they appear that they would pass unnoticed. There is a curious law in London which may prevent the shutting off of any light from the sky by buildings erected near windows that have been in use for a long period.

The St. James and Pall Mall Company has a station off Duke Street, near St. James Square. This district was pointed out several years ago by Prof. George Forbes as the most favorable quarter for a low tension system. Offices, clubs, fashionable private residences, and stores demand a large and continuous supply of current. The district is less than a square mile, and the station not far from its center. The site, which was occupied by a stable, is a court yard, which is to be vaulted entirely by iron girders on which the yard is to rest. Two locomotive 400 horse-power boilers are in one portion of the cellar. The remainder of the cellar already excavated contains ten 200 horse-power Willans engines. The exhaust steam escapes by a separate flue built onto the 140-foot chimney. Overhead travelers facilitate the handling of engines and dynamos. These rest on concrete 8 feet thick, and there is a trench the whole depth of the concrete around the engine room to stop noise and vibration. The company was several times complained of soon after it began operations in April, 1889, but on investigation it was found that the engines were not running at the times stated in the complaint. Great care is used in every installation to give no grounds for complaint, and contrary to what we have always supposed, the average Englishman has a vivid imagination for noises and disturbances that the less acute ears of Western nations would fail to notice. The dynamos by Latimer Clark, Muirhead & Company are of the Siemens type and, what cannot be said of all English machines, run cool. The electrical regulation is done by a potential galvanometer connected to pilot wires laid in the trenches with the feeder wires, and connected to them at the points of distribution. This potential governor makes contacts which set in motion in one direction or the other a little motor which throws in or out resistances in the circuit. The fuses are of lead wires, the ends of which are joined to solid lead strips. The instruments of the Cardew, Ayrton, and Perry types are complete and conveniently arranged.

Ascending from this basement by a winding iron staircase, a floor is reached, designed for accumulators. The next floor is filled with carriages, and the upper one with offices. The final capacity of this station has been carefully considered in its design, and is 13,200 horse-power or 2000 light dynamos, and by the aid of accumulators 50,000 lights can be supplied. All foundations and steam and exhaust pipes have been laid for the full capacity. The mains and feeders are bundles of bare copper strips in 150 feet lengths stretched tight with tackle and soldered, and supported at the ends of each section of conduit. This is of U shape, the sections being joined by iron saddles, caulked with lead. The cover fits into grooves, and is made water tight with hemp and red lead. At each saddle a porcelain separator with three grooves contains and supports the conductors. As the sections are about 10 feet long, ebonite separators are also placed on top in each section. Attachments are made by drilling, tapping, and bolting the house mains to the street mains. At low points the conduits and junction boxes are drained. The coal used in this station costs delivered 24 shillings, or \$6.00, per ton. The best Welsh navigation or smokeless coal must be used in London, and this, with the coal dues and expenses for teaming, makes the fuel bill more of an item in the expense account than would be the case with us if more economical engines were used. A second station is proposed in the northern portion of the district near Oxford Street.

The Kensington & Knightsbridge Company have at Kensington High bridge a station now in its fourth year, engineered and designed by Mr. Crompton. 7000 lamps were connected in July, and at the time of my visit, 6 P. M., with three hours more of daylight, the output of 50 amperes indicated that 100 lamps were in use. Three 90 horse-power Willans engines and three 550 ampere Crompton dynamos, and 2 sets of the Howell accumulators of 60 cells each formed the working plant. In July the starting hour is 7 P. M., and the machinery is stopped at 1 A. M., or when the cells become fully charged. During the remainder of the 24 hours the batteries supply current. These have an output of 100 per set. The batteries simplify regulation. The plant was being more than doubled in size, and Babcock and Wilcox boilers of 250 horse-power were being added. Other generating and storage battery stations are in process of erection or contemplated to supply this district. The cost of producing 1000

watts in Dec., 1888, was 2 cents, including all operating expenses and repairs, 5000 lamps connected and 67,500 units contracted at 16 cents per unit. The unit adopted by the Board of Trade and by one large parent company in this country is 1000 watts — 1 ampere at 1000 volts or any product of amperes and volts that will = 1000, and is nearly = 20 16 candle-power lamp hours or 100 cubic feet of gas. A dividend of 7 per cent was not distributed, but was devoted to extensions. The mains are laid in brick cemented culverts under the sidewalks. There is no depreciation to the insulating material which, as in the St. James Station, is that advocated by Captain Brophy, of Boston, i. e., dry air. The bare copper leads are supported by glass insulators.

The Crompton system embodies groups of storage cells charged in series and placed at convenient points for distribution, 4 or 8 batteries in series, and 550 to 1100 volts in the charging main. The first of the type of cell employed, which is of the Plante style, were formed *in situ*, and having no capacity acted at first as regulators and slight storage. A battery costing \$1000 three years ago is now valued at \$800. Cells of newer types have a discharge of 1000 amperes and depreciate less than 5 per cent. The need for storage is caused by the large output for a short time, about 7.30 P. M., when the servants are preparing dinner and others for dinner in the chambers. Drawing rooms and dining rooms are then lighted. The shops do not close until 8 o'clock. A few motors are operated, and for these in London there is not a very good field. Elevators have not to any extent taken the place of the good old-fashioned stairway, safe without inspection, and besides it is difficult to compete with hydraulic power from water distributed at 700 pounds pressure per square inch. A 60-foot passenger elevator costs for water \$36.00 per year by contract. The Kensington station has used the Aron meter exclusively.

"Dead as Chelsea" is not true of the part of London known by that name. Whatever may be said of the little city across the Charles and Mystic, Chelsea, Eng., is beyond all rivals the most enterprising electrically. On Manor Street is the plant of the Cado-gan Electric Light Company. Storage batteries made by the E. P. S. Co. are placed in each house supplied, the voltage 30, 48, and 96 volts is given by different numbers of cells. With an output of 70 amperes, from 35 to 140 are supplied in each house, and Aron meters

measure the current consumed. It is intended to make use of the Edmunds' distributing system, wherein the batteries in consumers' houses are divided in groups and charged a portion at a time, the switching being effected by a small motor. The system is unique, and, under the supervision of the managing director, J. S. Sayer, may supplant earlier systems. The "Leeds" dynamos give 400 volts 70 amperes, have Gramme ring armatures and run at 800 revolutions, and are belted direct to Armington and Sims engines, 50 horse-power built, as well as the dynamos, by Greenwood and Batley.

Years ago in England all large powers were transmitted by gearing, and it was thought impossible to use belts. This prejudice had exercised great influence in the introduction of direct coupled engines, and has almost entirely prevented the use of leather belting. So, in this station the leather belts and American engines and boilers of the Babcock and Wilcox type reminded one of home. In this station boilers, engines, and dynamos are in one large room. Three sets of accumulators, A, B, and C, of nine cells each supply 66 amperes for exciting the field magnets of the dynamos, and are charged at the same time they energize the fields. The Worthington steam pumps, in fact, everything, is American except the dynamos and cables. The cables are composed of 19 strands of No. 14 wire, with double rubber insulation, and suspended from iron fixtures on housetops and a few poles. The length of the three circuits is 9 miles, 1000 yards being under ground in plain iron pipes. Engines are started at 6 A. M., and stopped at 9.30 P. M. One circuit is charged in the morning, second in the afternoon, third in the evening. Three thousand lights are connected, and an increase ordered. \$12.50 per year per light is charged in bar-rooms, \$6.25 for private homes, or by meter at 15 cents per unit. The iron stack, stayed and guyed as if to last for a century, must be taken down in two years, and a brick one built. Iron stacks or chimneys are not quite English. Coal used is the best Welsh smokeless, and costs 23 shillings per ton. The cells always contain two days' supply, but are charged to the gassing point daily. Substations of batteries will be placed in stables behind the best houses, sufficient quarters costing \$75 per year. The overhead wiring is well done, the cables supported by leather from galvanized wires attached to glass insulators.

The Chelsea Electric Supply Company has adopted a system of

sub-storage stations, the inventor being Mr. King, of the E. P. S. Co. The main generating and storage station is at Draycott Place, Cadogan Terrace. The dynamos are built by the Anglo-American Brush Company. There is, as it were, a sub-station of accumulators in the same building. In the battery room there are 3 tiers of cells, in all 12 sets of 54 cells each. The cells are glass in wooden trays lined with sawdust. The boxes rest on glass insulators containing rosin oil. Each cell weighs 200 lbs., and is supported on wooden cross-pieces fixed to iron uprights. The regular discharge is about 60 amperes for 9 hours. Two sets run 3000 30-watt lamps of 13 candle-power. Traveling cranes assist in changing cells. The mains are laid under the sidewalks at the curb. Several sub-stations are undergoing construction, one was in operation at the time of my visit. It is situated in a stable at Clayton Mews. Eight sets of 53 cells each are attached to 2000 30-watt lamps, and furnish a constant and satisfactory supply of current. Ventilation is effected by a fan driven by a 1-8 horse-power motor, but is seldom necessary. The feeders are at times automatically joined to C. E. M. F. cells of plain lead grids.

In such a station the batteries are divided into two parts. When the engines start, one set is supplying current for day consumption, the other is thrown into circuit and is charged, then switched onto the mains, and the second set is switched on the dynamo circuit and charged, and when this is completed it is put in multiple with the first set and begins to discharge. This is accomplished before the heavy lighting begins. The cells are cut out of the charging circuit automatically, when charged, by a master cell from which the gas evolved raises a gas-holder and makes contacts that allow current to move switches. The regulating devices are exceedingly ingenious, and though somewhat complicated work well. A great future is before this system if, as seems likely, it stands the test of actual work for a long time. The E. P. S. Co. guarantees the cells to have less than 12 per cent depreciation.

House lighting in England is considered of the first importance in central station work, and the "House to House" Electric Light Supply Company has done good work in several cities. Its station at Brompton is a model one. It is designed for 12 complete sets of plants of which 3 are now running. Babcock and Wilcox boilers are used, connected by copper tubes to the main steam pipe of welded

steel. Copper tube for the entire steam piping is common practice in England. The temporary partition of corrugated iron at the end will give room for nine more boilers in addition to the three now in use. The chimney is large enough for six. All exhaust piping laid under the floor is large enough for 12 boilers. The three engines are compound non-condensing of the Corliss type, and belted to the dynamos by seven separate ropes. They are steam jacketed, and with 140 pounds of steam develop 250 to 300 horse-power.

The Lowrie-Parker dynamos have revolving fields and stationary armature and make 350 revolutions, producing 60 amperes at 2000 volts. The exciters are driven from a small counter on the armature shaft. The details of this system are well worked out. The dynamos are often run in parallel, a feat not attempted elsewhere. To determine when two dynamos are in step a lamp is connected to two secondaries in series, the primaries being one in the circuit of each machine. When the phases of the two dynamos coincide the lamp burns brightly, and the switches are then thrown. The mains are under ground, of stranded wires insulated with india rubber.

All of the stations described thus far in London are removed from supplies of water for condensing purposes, and where coal of extra quality must be used to prevent smoke nuisance. To attain the high degree of economy in condensation, to avoid the expense of carting coal, etc., the London Electric Supply Company located a station at Deptford, five miles from the city, to which a current of 10,000 volt alternating will be carried in concentric cables running by the viaduct of the South Eastern Railroad and the Underground Railroad to substations at Charing Cross, etc., and there transformed to reduce the pressure from 10,000 to 2500 volts, which is distributed by underground mains in bitumen conduits to consumers, and again converted to currents of 100 or 50 volts. So gigantic an experiment as this was not entered upon by chance. A small station in the basement of Grosvenor gallery became a success a few years ago when Mr. Ferranti's system was adopted. Over 30,000 lights are run from this station. The mains are overhead on housetops. The E. M. F. employed is 2500 volts, so that the Deptford installation is not wholly experimental. The saving in the cost of coal is as 22 shillings to 8 shillings 9 pence, or as \$6 to \$5.50 to \$2.18. The engines now operating are upright marine compound condensing Corliss, working

at 160 to 200 pounds pressure. Condensation is not yet provided for. The Thames water or sewage is very dirty, and it is necessary to go out 200 feet from the dock at low tide to find water, at which a mud beach extends 75 feet from the wharf,—a mud beach so soft that vessels are not injured by resting on it.

The compound engines and exciters would for a small town be a large plant. But the large dynamos recently started are 30,000 light machines, and these are small compared with the monsters in process of construction. They will weigh 600 tons. The armature will be 42 feet diameter and the frame 45 feet. The speed will be 50 to 60 revolutions. These engines being two of 10,000 horse-power to each machine directly connected. The crank shaft alone will weigh 26 tons.

The boilers of Babcock & Wilcox type, by means of forced draft obtained from blowers driven by engines under boiler room, are capable of generating 800 horse-power each. The gases from the furnaces pass at will through economizers to a 130-foot stack. When finished in two stories there will be 48 boilers. Railways connect every part of the works and yard. The engine room has two large overhead cranes. There is a 50-ton crane at the end of the wharf, and a 3-ton crane is mounted on a platform car.

The quality of incandescent light in London is inferior. The light is not steady, never above candle-power, but of a dull red color, and is often referred to by envious gas engineers as 4-watt red-hot hairpins. The expert, the bane of all electric companies in the United States, has a cousin in the engineer. They are of the same class as the experts, only they know less. The height of their ambition is to become "attached" to the staff of some noted engineer, and superintend or direct practical work without ever learning it by hard work and experience. Engine drivers earn 30 shillings a week; they are little more than oilers; fitters keep machines in repair; steam engineers overlook all this work; the engineers of the staff oversee the steam engineers, and the engineers in chief receive the salary and get the honors. Manual labor is deemed menial, and young men of the middle class shun it.

At the close of the paper a large number of views of the London stations were projected on the screen.

MEETING 404.

The Engineering Building.

BY PROFS. F. W. CHANDLER, G. LANZA, G. F. SWAIN, AND MR. S. H. WOODBRIDGE.

The 404th and annual meeting of the SOCIETY OF ARTS was held in the Engineering Building of the Institute on Thursday, May 8th, at 8 P.M., President Walker in the chair.

After the reading of the records of the previous meeting the report of the Nominating Committee was presented, and officers were elected for the ensuing year.

The report of the Executive Committee was read and ordered placed upon the records. The President then announced the subject of the evening to be the New Engineering Building of the Institute, and introduced Prof. F. W. Chandler, who described the architectural features.

Prof. CHANDLER said: The Engineering Building of the Institute of Technology is built on Trinity Place, a short distance from the other buildings of the Institute. The structure measures 148 feet by 52 feet, and has six stories. Its height of 85 feet is the extreme limit allowed by the building laws when a wooden construction is used. Its position on the lot was very carefully considered in regard to future additions to the south on the property of the Institute; and, by mutual agreement with the abutters, there will always be a clear area of 30 feet to the north.

The scheme of the building is what is known as modern mill construction. A row of cast iron columns, placed eight feet from center to center, runs lengthwise of the building, giving spans of twenty-four feet from column to wall. The strength of the brick wall is concentrated in buttresses opposite the columns, and thinner walls unite them, and because these thinner walls are not necessary for the stability of the building, the greater part of this space is occupied by windows, the heads of which extending between the beams, as there are no ceilings, to the underfloor gives that high light which is the most effective in lighting a large room. A pair of southern pine beams extends from each column to each side wall. These doubled beams

are in all cases bolted together with eight $\frac{3}{4}$ -inch iron bolts to each pair, leaving a space of one inch between for ventilation, kept open by iron washers. The beams are framed to fit snugly around the columns, and the ends of the abutting timbers are fastened together by dogs of $\frac{3}{4}$ -inch iron, the ends of which are turned down and driven into holes in the beams. These timbers are also fastened at the under side by lag screws through the caps of the columns. The other ends rest on cast-iron plates one inch thick, and are carried into the wall eight inches, and one inch of air space is left about the ends for ventilation. To tie these beams to the walls a one-inch bolt is put through each pair of beams eight inches from the wall, and at the same time through the eye of another one-inch bolt which lies between the timbers, the nut end being on the outside of the building, and pressing against a cast-iron washer. Across these paired beams are carried plank under-floors of spruce, four inches thick in the basement and three inches thick elsewhere. These planks are laid with splines. The upper floors throughout are of maple and $\frac{3}{4}$ inches thick. Between the lower and upper floors, in addition to the asbestos paper required by law, are three thicknesses of heavy deadening felt, and two of tarred paper.

The construction of the roof is like that of the floors.

It does not yet appear by whom the slow-burning construction, as applied to mills, has been evolved, or when was first made use of heavy timbers set wide apart carrying a solid floor. But for a long time after these floors were in use, even in Lowell, the roofs were bad either in form or structure until Mr. William B. Whiting, the Vice-President of the Boston Manufacturers Fire Insurance Co., suggested the adoption of what is called the deck roof, constructed like the floors, and the Engineering Building is a development of the Mutual Underwriters more than anyone else.

The structure throughout is of unusual strength, for the aim was to have a building which should be sufficiently free from vibration when the heavy machinery was running in the basement, to admit of experiments being made there, requiring delicate measurements, and because the four upper floors were to be chiefly used for draughting rooms. The iron columns decrease in size from the one in the basement measuring $11\frac{1}{2}$ inches in diameter with a $1\frac{1}{2}$ -inch shell to the one in the sixth story, 6 inches in diameter with an inch shell. These

columns resting on each other have their ends carefully turned in a lathe to ensure perfectly accurate bearings,—the head of one column having a seat countersunk $\frac{1}{4}$ inch to receive the foot of the next column. In the mill proper these columns are of wood, but, on account of the great weight to be carried in this structure, much valuable space could be saved by using iron.

The beams of the basement floor measure each 11 inches by 18, those of the first floor 10 inches by 18, those of the second 7 inches by 16, and those above 6 inches by 16, and those of the roof 6 inches by 14.

There are no boilers in this building, the steam for heating and for power is brought from the boilers in the basement of the Rogers Building, about a thousand feet away, through a six-inch pipe buried under ground. The pipe is first wrapped in asbestos, and for further insulation it is inserted in a wooden log.

The heating system is partly direct and partly indirect, and with the indirect part ventilation is obtained by means of a Sturtevant blower. Nearly all the radiators have automatic valves, the temperature of the room regulating the steam supply to the radiator.

In connection with the heating should be mentioned that the window sashes of the north, east, and west sides of the building, and also a large skylight on the roof measuring 80 by 16 feet, lighting the upper draughting room, are double glazed, making a great saving in the expenditure of heat.

The exterior design is very simple, all effect being obtained by the principle of construction. The solid basement from which rises the long buttresses or pilasters, connected at the top by semi-circular arches, and the upper story with its thinner wall forming an attic, describes the design. And it is effective enough; it tells its story truly. The material is rough brick with a small amount of long meadow stone trimmings.

A heavy block granite foundation rests on 725 piles, averaging 40 feet long. All the heavy machinery in the basement have their piled foundations distinct from that of the building.

There can hardly be a more fire-proof structure. First, its isolation; then there is not a concealed space anywhere, no furrings on the walls,—the brick is the only finish, no ceilings, with its dangerous air space the depth of the floor joists,—the staircase is built open in

the same way,—the ventilation and heating ducts running from the basement out through the roof are of iron. Water is on every floor, and the standpipe is carried to the roof. An iron staircase, built in a brick tower, runs to the roof to serve as fire escape.

The building is occupied by the Mechanical Engineering and Civil Engineering Departments. The two lower stories are the laboratories of the Mechanical Engineering Department, and this department also has the two middle floors, which are devoted to drafting and recitation rooms. The two upper stories contain similar rooms for the Civil Engineering Department, and the library common to both departments.

THE LABORATORIES.

Prof. Lanza was next introduced to describe the laboratories.

Prof. LANZA said: These laboratories are now called the Engineering Laboratories, and the building is called the Engineering Building, because it is especially devoted to the engineering work of the school, both the general and the special. Thus, in its recitation rooms are taught the classes in mechanism, in thermo-dynamics and steam engineering, in hydraulics, and in strength of materials, all of which may be called general engineering studies, as all these subjects are taught, to a greater or less extent, to the students of civil, of mechanical, of mining, of chemical, and of electrical engineering. Besides this, all the drawing-room work of the students of these courses is done in this building, and all the purely professional work of the civil and mechanical engineering courses is carried on here; this including practically all the *engineering* work proper of the above stated courses. Hence it follows that it is the building where the purely engineering work is done for all departments of the school.

The Laboratories are really an aggregation of the following:—

1. A laboratory devoted to experimental work upon the strength and other resisting properties of materials used in construction.
2. A laboratory of steam engineering.
3. An hydraulic laboratory.
4. A laboratory where other engineering experiments are made, but which is not yet sufficiently differentiated to be divided into its component parts.

The objects to be accomplished by these laboratories are the following:—

First. To give the students practice in such experimental work as any engineer is constantly liable to be called upon to perform in the practice of his profession,—as boiler tests, engine tests, power determinations, etc.

Second. To give the students some experience in carrying on original investigations in engineering subjects with such care and accuracy as to render the results of real value to the engineering community.

Third. By publishing from time to time the results of such investigations, to add gradually to the common stock of knowledge.

The two lower floors of the building are entirely devoted to the Engineering Laboratories, thus increasing their capacity from about 5,550 square feet, as in the Rogers Building, to about 13,900 square feet. Cuts of these laboratories are shown here, and the following statement of the apparatus they contain is copied from the twenty-fifth Catalogue of the Institute :—

“ The laboratory for testing the strength of materials is furnished with the following apparatus. An Olsen testing machine of 50,000 pounds' capacity, for determining tensile strength, elasticity, and compressive strength. A testing machine of the same capacity for determining the transverse strength and stiffness of beams up to 25 feet in length, and the framing-joints used in practice. Machinery for the measurement of the strength, twist, and deflection of shafting while running and under the conditions of practice. Machines for time tests of the transverse strength and deflection of full-sized beams; for testing the tensile strength of mortars and cements, and of ropes; for testing the effect of repeated stresses upon the elasticity and strength of iron and steel; for determining the strength and elasticity of wire; for determining the deflection of parallel rods when running under different conditions. Also, accessory apparatus for measuring stretch, deflection, and twist.

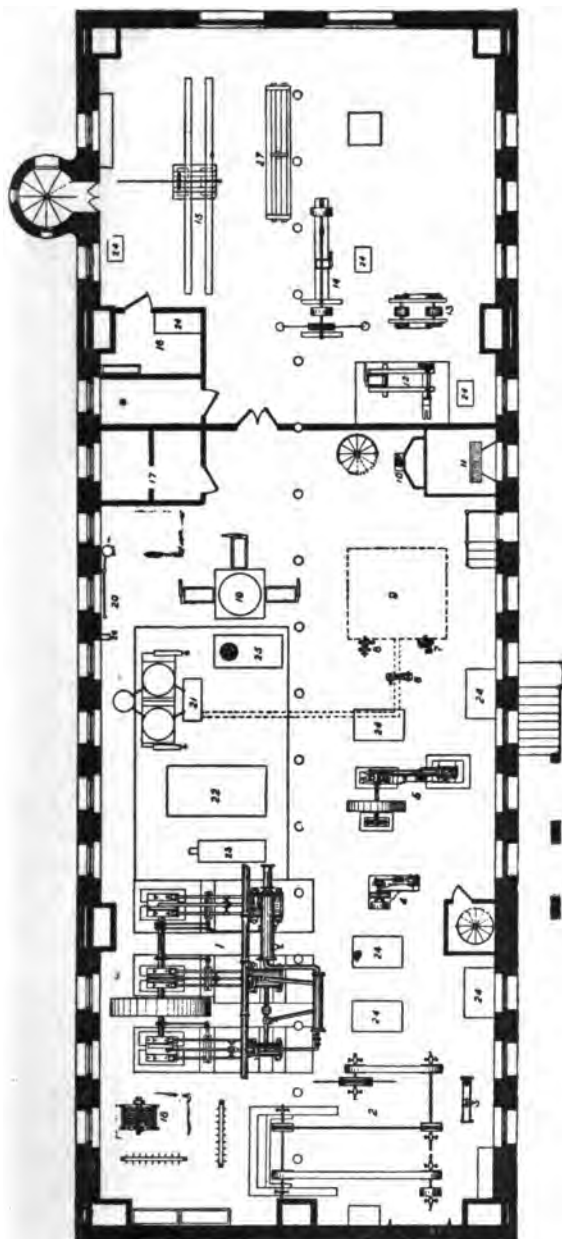
“ The steam laboratory contains,—a triple expansion engine, with cylinders of 9 inches, 16 inches, and 24 inches diameter respectively, and 30 inches stroke, arranged in such a way as to be run single, compound, or triple, as desired for the purposes of experiment. This engine is of the Corliss type, and was built by E. P. Allis & Co. It will have a capacity of about 150 horse-power when running triple, with an initial pressure of 150 pounds in the high-pressure cylinder. It is connected with a surface condenser and all the other apparatus necessary to adapt it to the purposes of accurate experiment.

"This laboratory also contains a 16 horse-power Harris-Corliss engine, and an 8 horse-power engine, used for giving instruction in valve-setting, etc. It is also equipped with several surface condensers, steam pumps, calorimeters, mercurial pressure and vacuum columns; apparatus for determining the quantity of steam issuing from a given orifice or through a short tube under a given difference of pressure; apparatus for testing injectors; and with indicators, planimeters, gauges, thermometers, anemometers, and other accessory apparatus.

"The engineering laboratories are also provided with a number of friction brakes; with machinery for determining the tension required in a belt or rope to enable it to carry a given power at a given speed, with no more than a given amount of slip; with three transmission dynamometers; with a complete set of Westinghouse air-brake apparatus, including the parts belonging on the car and on the locomotive; with cotton machinery as follows, namely, two cards, a drawing frame, a speeder, a fly frame, a ring frame, and a mule, as well as accessory apparatus. There are also available for the purposes of experiment, in connection with the work of these laboratories, two horizontal tubular boilers, one large Babcock and Wilcox boiler, and a Porter-Allen engine of about 80 horse-power, all situated in the Rogers Building; also another boiler, a 40 horse-power Brown engine, a number of looms, and other apparatus in the workshops on Garrison Street."

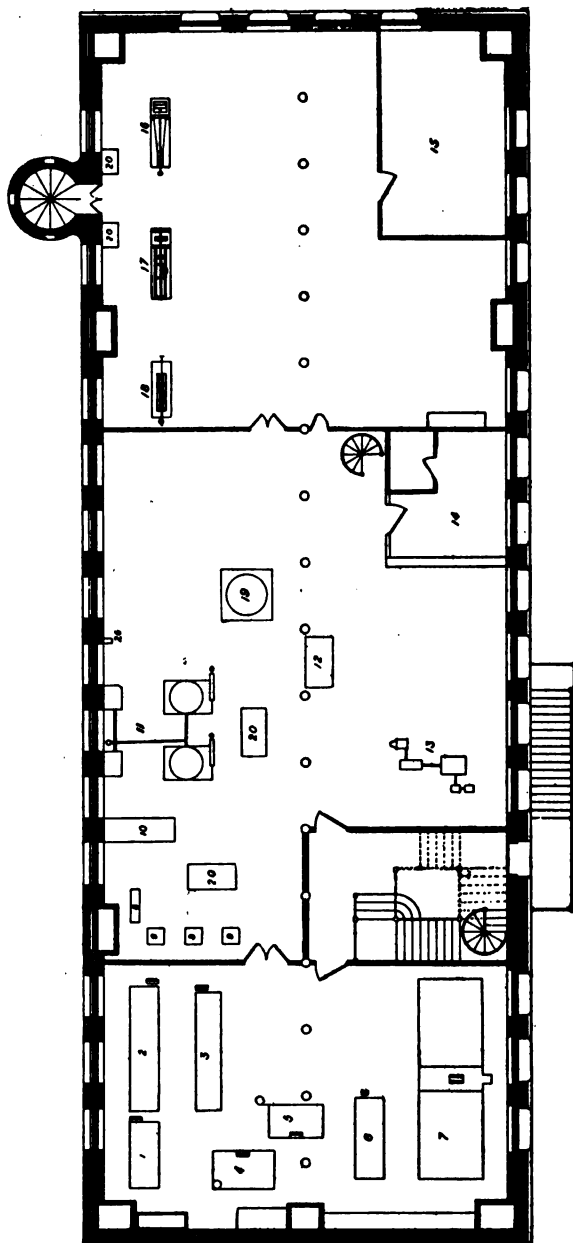
The most important addition to the equipment of these laboratories is that of the triple-expansion engine, inasmuch as it is the first triple-expansion engine of a practical size that has ever been arranged for making experiments; and by its means the laboratories are placed in a position which will enable them to do work for the triple engine of a character similar to that done for the compound engine by the United States Naval Engineers in 1874, and also to make such researches with a triple or a compound engine as were made upon single engines by Hirn, Hallauer, and others.

The laboratory with its present equipment furnishes the means, — 1st, of accommodating the number of students that now need this instruction, with an opportunity for some growth; 2nd, of giving good laboratory instruction to the students; 3rd, of carrying on investigations of importance in the engineering line. All this can be done, inasmuch as the building is adapted to the purposes of an engineering laboratory,—a fact which was never true of the Rogers Building.



BASEMENT, 150 X 50 FEET.

1. Triple Expansion Engine, 150 H. P.
2. Rope and Belt Transmission Testing Machine.
3. Engine Lathe.
4. Kendall Engine, 8 H. P.
5. Harris-Corliss Engine, 16 H. P.
6. Steam Pump.
7. Rotary Pump.
8. Centrifugal Pump.
9. Tank.
10. Fan Engine.
11. Steam Pipes for Heating Air.
12. Rope-Testing Machine.
13. Parallel-Rod Machine.
14. Sharpt-Testing Machine.
15. Fifty Thousand Pounds Beam-Testing Machine.
16. Cement Room.
18. Dynamo, 500 Lights.
19. Wrought-Iron Tank for Hydraulic Experiments (5 feet diameter, 27 feet high).
20. Hydraulic Stand-Pipe (10 in. diam., 85 feet high).
- 21, 22. Cisterns.
23. Condenser.
24. Tables.
25. Turbine-Wheel and Tank.
26. Mercury Column.
27. Apparatus for Time Test of Wooden Beams.



FIRST FLOOR.

- | | |
|----------------------------------|--|
| 1. Drawing-Frame. | 15. Office. |
| 2. Speeder. | 16. Olsen's Fifty-Thousand Pounds Tension Machine. |
| 3. Fly-Frame. | 17. Repeated-Bending Machine. |
| 4. Carding Engine. | 18. Cement-Testing Machine. |
| 5. Carding Engine. | 19. Tank for Hydraulic Experiments. |
| 6. Spinning Frame. | 20. Tables. |
| 7. Mule. | 21. Mercury Column. |
| 8. Calorimeters. | |
| 9. Calorimeters. | |
| 10. Calorimeters. | |
| 11. Injector and Weighing Tanks. | |
| 12. Tank for Turbine-Wheel. | |
| 13. Westinghouse Air Brake. | |
| 14. Office. | |

THE HYDRAULIC LABORATORY.

At the close of Prof. Lanza's remarks, Prof. G. F. Swain was introduced, who described the Hydraulic Laboratory.

Prof. SWAIN said: The erection of the new engineering building of the Institute of Technology, to be occupied by the departments of Civil and Mechanical Engineering, offered an opportunity for a considerable extension in the Engineering Laboratories, and an attempt has been made to improve this opportunity by laying the foundation for a laboratory for hydraulic experiments, which should be so arranged as to permit of the carrying out of any experiments in hydraulics which it is practicable to perform within walls. Hydraulic experiments on a large scale must necessarily be performed out of doors, since the measurement of large quantities of water requires apparatus and appliances which cannot be accommodated within walls. Thus, the weir experiments of Mr. Francis, at Lowell, were made by taking the water from one of the canals, and using a lock as a measuring basin; those of Messrs. Fteley and Stearns, at South Framingham, were made by using a portion of the Sudbury River Aqueduct as a measuring basin; the orifice experiments of General Ellis, at Holyoke, were made in connection with the fall between two levels of the canal at that place; and the recent elaborate and careful experiments by Mr. Freeman on the flow of water through fire hose, the discharge of nozzles, and the height of jets, were made at Lawrence, where the hydrant system of one of the mills, as well as the city water supply, could be made use of.

But while experiments such as these are clearly excluded from among those which can be made in connection with a hydraulic laboratory in an institution of learning, there remain a large number which can properly be conducted within doors with the aid of suitable apparatus, and which, though they may be on a small scale as regards the quantities of water employed, nevertheless offer a large field for scientific investigation. The new laboratory of the Institute, as already stated, has been planned with a view to affording opportunity, as the work is extended, for carrying on any experiments which are thus practicable; that is to say, in the following directions:—

1. Experiments on the flow through orifices of small size, both free and submerged, and either sharp-edged, rounded, or fitted with

inside or outside mouth-pieces of various kinds, and under heads ranging as high as above seventy feet.

2. Experiments on the flow of water over weirs of small size, either free or submerged.

3. Experiments on the loss of head in small pipes of various kinds.

4. Experiments on the loss of head due to bends, curves, valves, diaphragms, or other obstructions causing sudden changes of velocity.

5. Experiments on the distribution of velocity in different parts of a liquid cross-section, either of a jet from an orifice, of a sheet discharged over a weir, or of a liquid flowing in a pipe.

6. Experiments on different water meters, including Mr. Herschel's Venturi meter, as well as the ordinary forms in the market.

7. The testing of small turbines and of various other small motors.

8. Experiments on the pressure of jets against plane or curved surfaces, and on the resistance of standing water to the motion of surfaces of different shapes through it.

9. Experiments on the siphonage of traps, and on other matters connected with plumbing arrangements of houses.

The development of a laboratory which shall admit of experiments in all these lines must necessarily be slow and expensive, and the laboratory in the Institute, being only a few months old, is not yet fully equipped to carry on any of these experiments excepting those on the flow of water through orifices. It is believed, however, that the foundation has been laid for the rapid development of research in the remaining directions which have been enumerated, and the object of the present paper is briefly to describe and illustrate the apparatus thus far provided or proposed.

In order to be able to work with large heads, and to be independent of the city water supply, as well as to provide for the varied experiments enumerated, it was first necessary to erect a tank and standpipe. The tank is shown in Figure 1. It is made of "Shell" steel $\frac{1}{4}$ inch in thickness, is 5 feet in diameter and about 28 feet high, resting on a concrete foundation and extending up through two floors. It consists of six courses of steel, with girth seams single riveted, and longitudinal seams double riveted, and with heads of $\frac{1}{8}$ -inch steel dished, as shown in the figure. It is provided with orifices as follows:—

In the lowest course, a man-hole 24 inches by 12 inches at M; at P, a flanged nozzle with elbow for connecting to 10-inch standpipe, as shown in Figure 15.

In the second course, a 10-inch orifice at G, a second at F, a third at D, and a fourth at C. The orifice at F may be used, if desired, for connecting with a small turbine placed below the floor. That at G is for experiments on submerged orifices. Those at D and C are for experiments on free orifices, or for connecting lines of pipe with the tank. Enclosing the orifice at G, an angle-iron and two bent plates are attached to the side of the tank, as shown, to which a wooden tank extending horizontally and resting on the floor is to be attached. In this wooden tank will be placed a weir, and the water will flow through the submerged orifice at G, or through a submerged mouth-piece, either inside or outside, and either converging or diverging, and will then flow over the measuring weir. The orifice C is fitted for experiments on free orifices, as will subsequently be described. The orifice D is to be fitted with a piece to which pipes can be attached as desired, thus enabling the losses of head at diaphragms, valves, curves, etc., to be studied. On the same level with the orifices D and G connections are made for mercury gauges.

In the third course, a $1\frac{1}{2}$ -inch orifice at G' and another at C', nearly above the large orifices G and C. These small orifices are for the shafts of the hand-wheels for raising the gates over the large orifices, as will presently be explained.

In the fifth course, orifices similar to those in the second course; and in the sixth course, orifices similar to those in the third course; thus rendering it possible to carry on experiments simultaneously upon two floors of the building. The top of the tank is provided with a flanged nozzle for connecting with the 10-inch standpipe, as shown in Figure 15.

The size of the tank is such that, with the orifices which it will be practicable to use, the velocity in the tank will be so small that it may be neglected, and the disturbance due to the inflowing water from the standpipe will also be small. Nevertheless, two gratings have been arranged, one at the top and one at the bottom. These gratings consist of plates of $\frac{1}{8}$ -inch iron perforated by $\frac{1}{2}$ -inch holes about an inch apart. They are made in three pieces, and rest upon angle-iron brackets riveted to the inside of the tank. The tank itself rests upon cast-iron supports, as shown in Figure 1.

The general arrangement of the tank and standpipes is shown in Figures 15 to 18. Figure 15 shows the plan of the sub-basement, with the location of the tank, the rotary pump, and the steam pump. The tank *a* is connected, as shown, by the top connection *e* and the lower connection *f* to the 10-inch wrought-iron standpipe *b*, which, as shown in Figure 17, extends to the top of the building, and is closed at the top. The connection *f* is tapped by the small pipe *g*, by means of which the water may be drawn out of the system into the cistern *h*. The pumps take water from this cistern *h* and deliver it into pipe *k*, which, as shown in Figure 17, is arranged to carry it directly to the standpipe through the valve *s*, or to the 3-inch pipe *c* through the valve *t*. For use in the hydraulic experiments, the valve *s* is closed and the valve *t* opened, the water being thus delivered into the 3-inch pipe *c*. From this pipe the flow into the 10-inch pipe is regulated by the valves *n*, which enable the head in the 10-inch pipe to be maintained at an almost perfectly constant level. Any excess of water overflows through the pipes *m* into the discharge pipe *d*. The pipe *c* therefore serves as a regulator of the head, and it has been found to fulfil its purpose admirably. Attached to the standpipe *b*, and running from floor to ceiling, in each story, is a glass gauge placed in front of a graduated scale reading to hundredths of a foot. These gauges are enclosed in wooden boxes, which may be opened on the front and on one side, and which are placed so as to receive light directly from adjacent windows. The water is taken by the pumps from the cistern *h*, passes through pipes *k* and *c* and through the valves *n* into the standpipe *b*, thence through the connection *e* or *f*, or both, into the tank, from which it is discharged through orifices, or in any other way desired, and the discharge measured. Measurements are made by weighing the quantity of water discharged in a given time, the water being returned to the cistern *h*, and thus used over and over again.

The same apparatus, by suitable arrangement of the valves, will be employed in making tests of the pumps.

The city water pipe is connected with the standpipe system at *x*.

The soil pipe *dd* is arranged with single and double Y's in a way which will allow the carrying out of all kinds of experiments on the siphonage of traps, as mentioned under head 9 on page 138. This pipe is arranged with an ordinary trap at the foot, as shown in Figure 16, and it discharges into the cistern *h*, as shown in Figure 15.

The details of the arrangement for measurements with simple free orifices are shown in Figures 2 to 14. In experiments of this description it is of course essential that the orifice shall be placed in a plane surface. It was therefore necessary to arrange the apparatus so that the curvature of the tank itself should not affect the flow. For this purpose a composition casting *a* (Figs. 2 and 3) is drawn up to the tank by eight $\frac{5}{8}$ -inch bolts, as shown in Figure 3, which are screwed into the hub of the casting. The greater part of the casting is only $\frac{1}{4}$ inch in thickness, with eight strengthening ribs, as shown in Figure 2. In this casting is placed a piece, *c*, which is held in position by a ring-nut, *dd*, which can be screwed or unscrewed by a spanner. When it is desired to use large or long orifices the piece *c* will contain the orifice, and by having various pieces *c*, with orifices of different shapes and sizes, numerous experiments may be carried out. The composition casting *a* is thickened on one side to $\frac{3}{8}$ inch, as shown in Figures 2 and 3, to allow of the insertion of a sliding piece by means of which the horizontal dimension of a rectangular orifice may be varied, keeping the vertical dimension constant. When small orifices are to be used, it is not desirable to have them cut in as large a piece as the piece *c*. This piece *c*, therefore, as shown in Figure 3, is arranged to take a second piece, *o*, held in place by a second ring-nut, *d'*. Small orifices are made in pieces like the one *o*, as shown in Figure 3, and are of different sizes and shapes.

It is desirable that one orifice may be removed and another substituted in its place without completely emptying the tank. For this purpose a gate is designed to slide on the back of the casting *a*, so that, when it is desired to remove one orifice, the gate may be lowered and the water thus shut off, and a new orifice substituted in place of the old one. The gate may then be raised and the experiments continued. This gate and the fittings connected with it are shown in Figures 4 to 14. Figure 4 shows a view of the gate from the inside, Figures 5 and 6 horizontal cross-sections, and Figure 7 a vertical cross-section. The gate is of cast iron, ribbed as shown, and is arranged to slide in guides bolted at the bottom to the casting *a*, and at the top to the tank. These guides are shown in Figures 8 to 11. In order that the gate may be raised without having to overcome the friction due to the pressure of the water over the entire surface of the gate, the rod *r*, by which the gate is raised, is attached to an

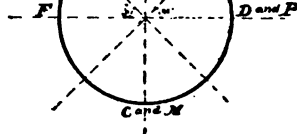
angle-iron, L (Figs. 4 and 7). When the gate is to be raised from the position shown in Figure 7, the angle-iron L is first raised until it strikes against the rib above it. This raising of L opens the orifice d , thus allowing water to pass through the gate, and equalizing the pressure on the two sides, except over the small ring forming the bearing surface, the friction due to the pressure on which is, therefore, the only friction to be overcome. The discharge orifice may be meanwhile closed by a plug from the outside, if necessary. When the gate is lowered, its own weight carries it down until it reaches the stop s . The rod is then forced down, closing the orifice d . Figures 12 to 14 show the hand-wheel, shaft, and stuffing box, by means of which the gate is raised, and require little explanation. The rod shown in Figure 7 is in its upper part a rack running in the space r (Fig. 12).

Only one further point calls for explanation regarding the arrangement of the gate and stuffing box, namely, the modifications necessary for the case of inside mouth-pieces. When such mouth-pieces are used, the gate as shown would of course be inapplicable, and a new seat must be provided for it, so that it will pass clear of the inside mouth-piece. It is intended to accomplish this by bolting on to the composition casting a (Fig. 2) a circular channel-shaped rib, and adding new guides for the gate, thus making its seat at any desired distance back of the inside face of the casting. At the same time, in Figure 12, the pinion will be removed from the position shown, and placed outside of the bearing, where the collar is shown in the figure, and the collar placed on the inside. A new guide for the rack will then be bolted on, as shown by the dotted lines.

As the new engineering building has been occupied only since February, 1890, and the hydraulic apparatus is thus but a few months old, the only apparatus thus far in use is that for measuring the flow through simple, free orifices, and for making tests of pumps. It is hoped, however, that the remaining apparatus will be provided in the near future. The tank and the standpipe system already procured furnish the foundation, and upon them the other apparatus may readily be built up. Experiments upon meters and upon motors may also be carried out without difficulty; and, in fact, the possible lines of research are so varied that it is hoped that the establishment of this laboratory may lead to many useful results, and that it may contribute in some measure to the advancement of hydraulic science.

Fig. 1.

9-18



Details of House Casting

Fig. 1
Horizontal Section

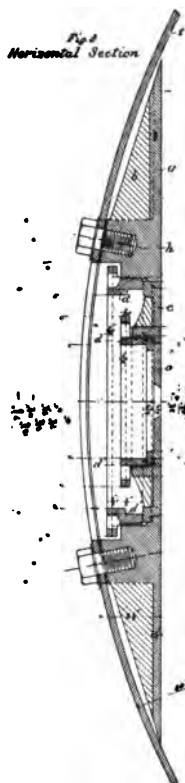
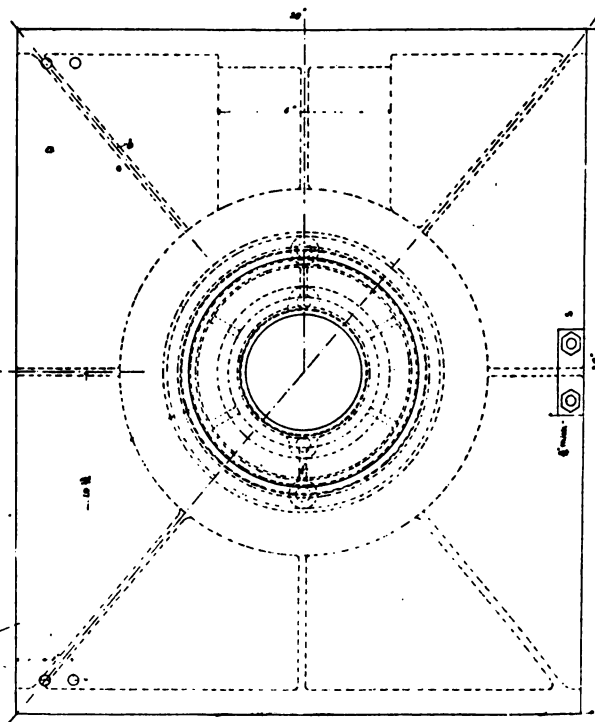
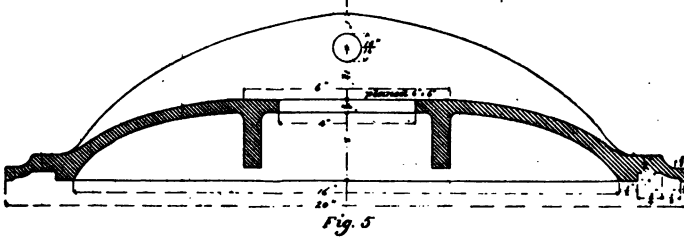
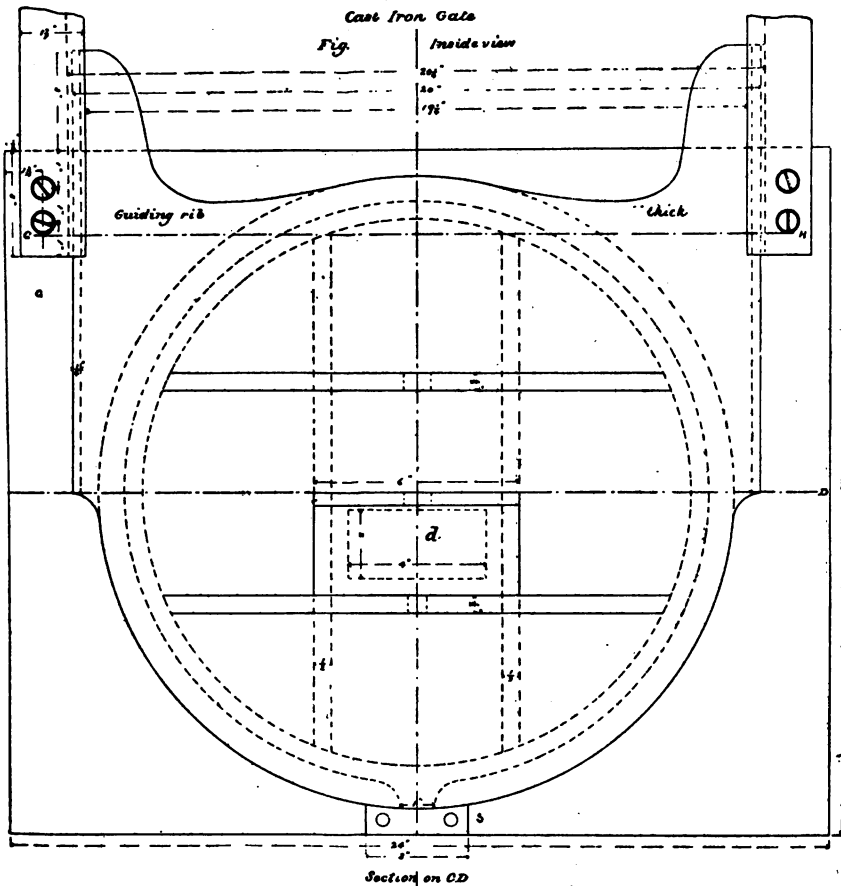


Fig. 2
Inside View





Section on G.H.



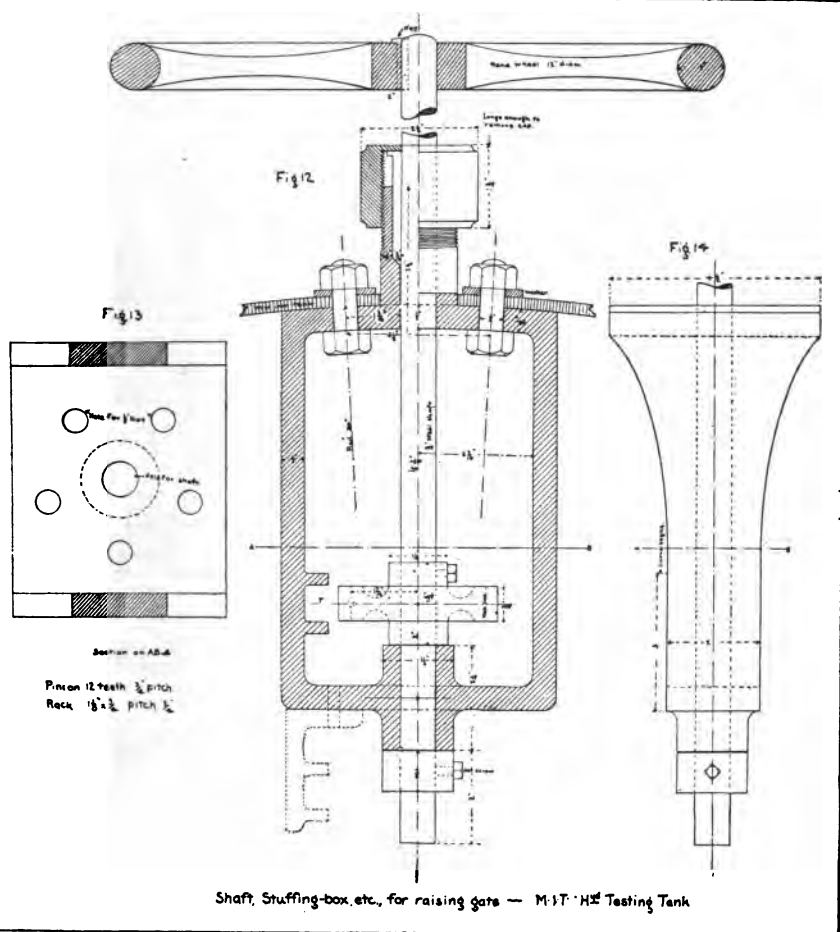
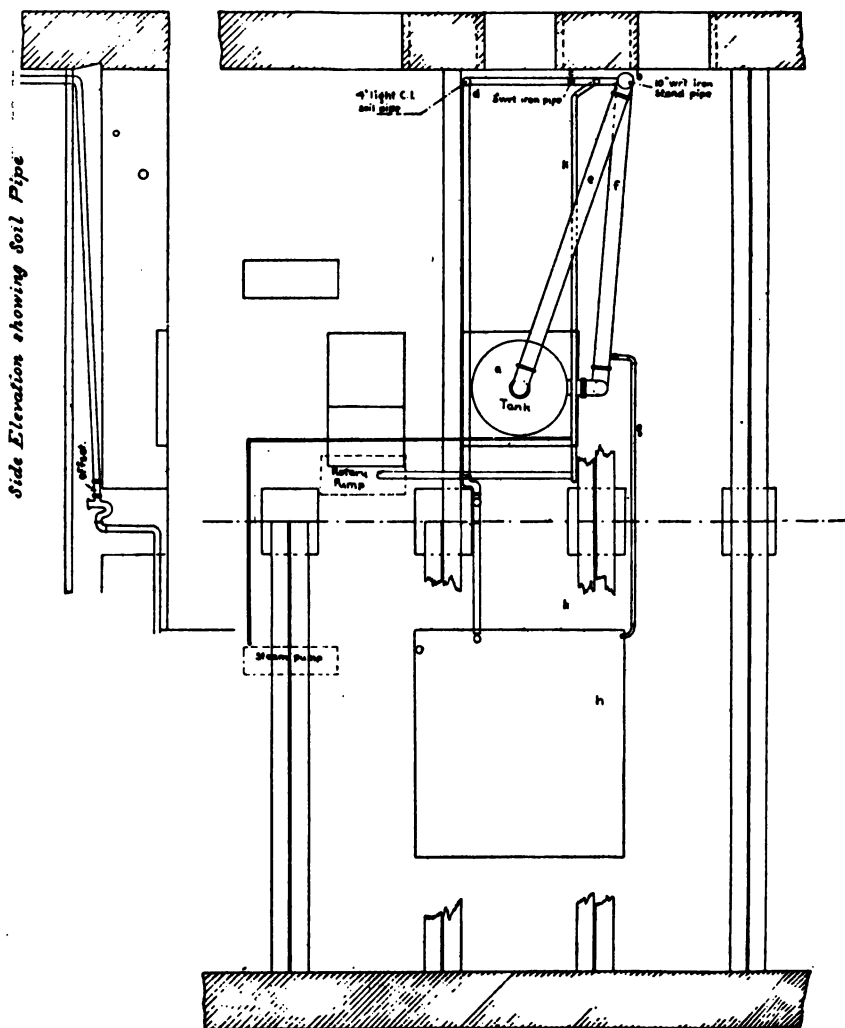


Fig 15

Plan of Sub-basement

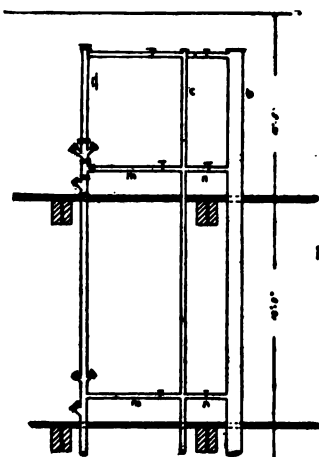


Fig 17

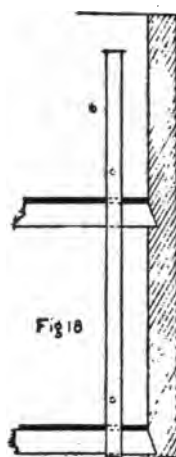
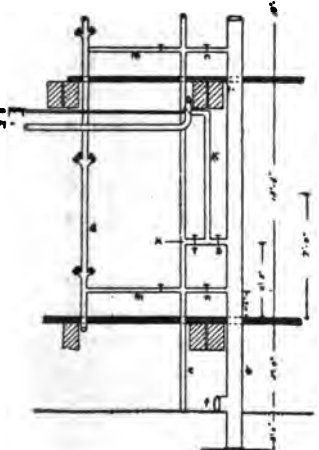
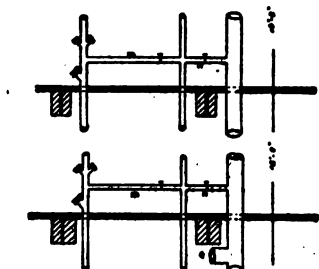
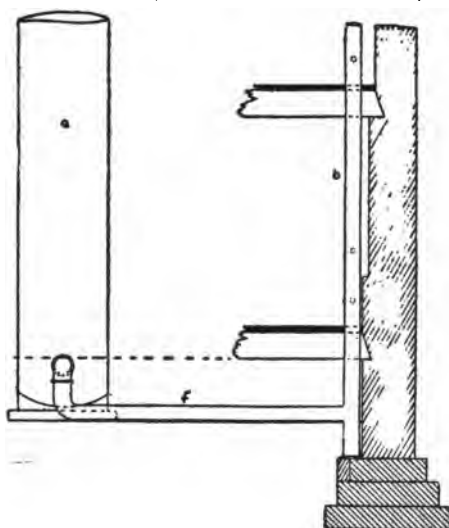
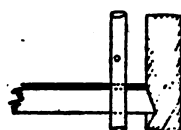


Fig 18



HEATING, HEAT REGULATING, AND VENTILATING.

At the close of Prof. Swain's paper, Mr. S. H. Woodbridge was introduced, who described the System of Heating, Heat Regulating, and Ventilating.

Mr. WOODBRIDGE said: This building is without interior walls other than light partitions, and all available external wall space is demanded for piers and windows. Locations were allowed for eight vertical flues (F) Fig. 1, varying from 9 to 12 sq. ft. in cross-section, for the supply and discharge ventilation of the thirty and more rooms. The rooms were arranged by their intended users with only partial reference to the fixed location of flues, and connecting air ducts were disapproved as unsightly. The great value of the basement floor space imposed a limit of 10' x 12' on the area to be surrendered to ventilating purposes. The use of the concrete floor of the sub-basement for apparatus, above and about which the basement floor is removed, precluded the use of this space as a distributing air chamber, and compelled the building of a continuous duct about the perimeter of the sub-basement, with one cross duct beneath the fan and into which it discharges at A-A, Fig. 1. The main duct, except where engine beds encroach upon it, is 15 sq. ft. in cross-section. The cross duct has nearly twice that area. The control of the air quantities to be moved in one direction or another within these ducts is effected by movable deflectors, one under the fan, and one at each end of the cross duct, Fig. 1.

The perimeter ducts have for three of their sides the foundation wall of the building, the sub-basement concrete floor, and the wooden floor of the basement. The fourth side is of galvanized iron, secured by nailing to wooden strips set in the concrete and nailed to the wooden floor and beams. A free use of elastic cement was made in all joints between metal and wood, and of paint in all locked or other joints of the sheet metal, and provision made for a possible settling away of the concrete from the wooden floor.

To clear the laboratory ceiling and the floor space of all possible obstructions and the unsightly appearance of piping, the steam mains and branches, traps, etc., are placed within the air conduits. All such steam pipes are carefully pitched and drained and covered. In spite of the latter precaution the temperature of the air in transit from the fan to the most remote flues is raised some 12°.

The eight vertical ducts are of necessity made to serve the dual purpose of supply and discharge. To adapt them to such purpose, a diaphragm is fixed in such way as to provide two channels having areas proportioned to the quantities of fresh and spent air to be moved through them to and from the successive stories, Fig 3. These diaphragms are made of sheet iron, which is secured by methods effectually preventing the leakage of air from the plenum into the exhaust conduits. Wherever practicable, the diaphragm is so placed as to remove the supply conduit from the outer walls, and to bring the discharge conduit against them.

Because of the small space occupied by the entire system, velocities of the air moved must be high. To secure to each register of the lower stories its proportion of air, and to prevent its going by such register under the momentum of its movement, deflectors are used, the area of each and the angle at which it is set controlling the air volume issuing from each register. Similar deflectors, set in a reverse position, are used for the outlets from the upper stories. To thoroughly break up and diffuse the swift flow of cool air in solid current from the register, diffusers, such as are shown in Fig. 1, are used with gratifying success.

The building accommodates some three hundred students, and the air supply is nearly 2,000,000 cu. ft. per hour, the fan running at 250 revolutions. The students are massed now here now there in class rooms, drawing rooms, and laboratories. Provision is made for a corresponding distribution or concentration of air supply, but the results without such alteration are so generally satisfactory that the valves are not used. Within the best filled rooms the largest proportions of carbonic acid thus far found are 10000 to 10000, and the uniformity of the proportions in all parts of the rooms has been found exceptional.

The warming is effected by three systems. Because of the large amount of steam work done in the basement, air must be supplied in large quantities, and at a temperature ranging from 45° to 55°, according to laboratory work and outside conditions of weather. The eight distributing flues cannot supply air to the several floors or rooms at different temperatures. They must supply it at the temperature required by that room above the basement most easily warmed to the point desired. Therefore, it becomes necessary to provide means for supplying air through one system of conduits to the basement at, say

50°, and to all rooms above the basement at 70°, and to further warm the air by direct means in such rooms as require supplementary heat.

The air is heated before it reaches the fan to 50°, a "Standard" metallic thermometer mounted in the fan case indicating the temperature, which is controlled by regulating the steam pressure in the coil. In moving under pressure through the sub-basement conduits the air leaks generously, as was anticipated, through innumerable small vents, the current being no where sensible, though the aggregate volume amounts to some 750,000 cu. ft. per hour. Reaching the base of the flues, the air passes through steam coils so made and placed that the flue area is not obstructed. The control of steam to these coils is by means of the Johnson electric regulating apparatus, the thermostat being hung on a crane before the supply register on the third floor. Whatever the temperature in the sub-basement conduits, the air supply to the rooms may be maintained at 70° or 72°, the range being confined within these limits by the automatic action of the regulator.

Within the rooms are placed wall steam pipes, the steam supply to which is regulated by the Johnson automatic apparatus, the thermostat being exposed within the rooms. For the quick warming of the building, the sub-basement conduit temperature may be run up to 100°, and the flue thermostat may be swung away from the register front. Air at such times may be rotated through the building instead of being taken from the outside.

The construction and arrangement of the auxiliary heater, Fig. 4, at the base of the flues is a matter of interest, because well suited to a successful working of the automatic method of steam supply. The steam enters at the top and through a valve so throttled that when the main conduit air is at its coldest the steam flow will be nearly continuous. The coil drains through a check valve. Without such an arrangement the temperature within the flue would fluctuate through a considerable range, for on the wide opening of the supply and return valves steam would enter freely at both ends and suddenly heat up the coil and the flue. It is desirable that the steam flow should be as nearly continuous as possible, and sufficient in quantity to warm the air passing through the coil. If the supply-valve is throttled, the drip-valve must be closed until the pressure within the coil is sufficient to force the accumulated water outward against the steam pressure. A

throttled drip-valve would allow steam to back into the coil and cause pounding. But the check-valve holds back the steam and allows the condensation to collect until its weight and the steam pressure combined force the valve open and the water out. The filling of the pipes with condensed water serves also the useful purpose of automatically regulating the length of their heated parts, and aids in maintaining the even temperature sought in the flues.

The heating is for the most part done by the exhaust steam of engines and pumps used in the building, and to avoid the possibility of returning oily water to the boiler the condensation is passed into the sewer. For the purpose of cooling this water, and of utilizing its heat, it is passed through 800 feet of continuous $1\frac{1}{4}$ " pipe, made into a trombone coil 38 pipes high, 7' long, and 3 pipes deep, placed before the inlet window, Fig. 2. In mild weather the condensation is so small that it goes to the sewer cold. When the outside temperature is low that of the chilled water is higher, the rate of condensation slightly exceeding that of the chilling. The maximum rate of flow in severe weather is about 1 cu. ft. per minute.

The fan and combined heater, with directly attached engine, is of the Sturtevant pattern and make, with a large by-pass over the heater. The fan is 6' in diameter, and at 250 revolutions per minute supplies 33,000 cu. ft. of air. Outside the inlet window a roaring sound of rushing air may be heard, due to the high velocities inflicted on the air in transit through the coil and fan because of want of space to give it larger passage and lower velocity. Within this sound is not heard, partly on account of the noise of moving machinery.

The low pressure under which the heating system is worked and the irregular flow of condensed water, due in part to the intermittent supply of steam to the pipes, make the use of any ordinary steam trap impracticable. The method adopted for the relief of the New Building system having given entire satisfaction, it has been adopted in this system also. It consists of a syphon trap made of a 4" pipe 18' long driven vertically into the ground, bushed at the top and tapped at the side. Through the bushing runs a $2\frac{1}{4}$ " pipe to within 1' of the bottom of the large pipe. This pipe is bushed at the top, tapped at the side, and open at the bottom. The tap receives the water from the returns. The bushing receives a 1" pipe, which drains the supply main at a higher pressure than the return, and runs inside the $2\frac{1}{4}$ " to within 1'.

of the bottom of the large pipe. Within the trap there may, therefore, be two pressures and two heights of water columns on the steam side, one vent discharging the water of both. The only resistance or friction is that due to the flow of water through the large pipes.

All steam for the building is brought from the Rogers building through an underground 6" pipe, about 1000' long. The water condensed in the heating apparatus is metered, and the record preserved for the purpose of record and investigation.

The cost of the complete instalment was nearly as follows :—

Fan, engine, main coil (1000 square feet), cooler, &c., . . .	\$1445
4580 sq. ft. of direct steam surface, flue coils, mains, fittings, and placing, ...	4490
Construction of ducts and sheet-iron work, ...	900
Johnson's electric service, ...	1355
Pump, Locke's regulators, sunken siphon-trap, covering mains, &c., ...	1775
Total, ...	\$9,965

The direct heating surface is as great as though the heating of the building depended solely upon it, as insufficient boiler power threatened to make the use of the ventilating system impracticable in severe weather. Furthermore, if air is passed into the rooms at the temperature at which it is desired to keep such rooms, to maintain that temperature, the direct surface must be as large as would be required for heating by direct radiation.

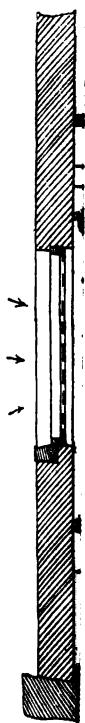
The system is practically a dual one, the capacity of either part being enough for the heating of the building. The ventilating system includes the main heater, cooler, fan, engine, duct, supplementary heaters in flues, &c. Its cost may be put at \$3500, and the balance may be charged to the heating plant. The total heating surface is about 1 sq. ft. to 110 cu. ft. of space.

Handicapped by the conditions imposed, the work is of interest not so much as an illustration of a perfect system as of what may be accomplished under difficulties.

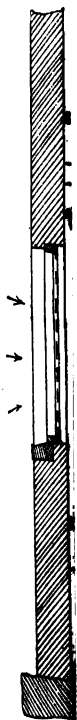
The following table puts the arrangements for the ventilation of the New Building in contrast with those for the Engineering Building :—

	New Building.	Eng. Building.
Area of inlet windows, ...	106 sq. ft.	33 sq. ft.
Area through steam coil, ...	120 "	20 "
Area of fan mouth, ...	65 "	13.3 "
Area of fan discharge, ...	150 "	12.2 "
Area of floor occupied by fan room and heating chamber, ...	720 "	120 "
Area of main heating coil, ...	2200 "	1200 "
Area of flues for supply and discharge of air, ...	240 "	96 "
Number " " " " " " " "	83 "	8 "
Air volume supplied, cu. ft. per hour, ...	3,600,000*	1,950,000
Fan revolutions, ...	80 to 100	250

* In mild weather this is increased to 6,600,000,— fan revolution 100, and indicated horsepower expended 17. The fan is now run by an independent engine, and not as heretofore at a fixed speed.







MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

ABSTRACT OF THE

Proceedings of the Society of Arts,

WITH LIST OF OFFICERS AND MEMBERS,

FOR THE TWENTY-NINTH YEAR.

1890-1891.

MEETINGS 405 TO 418 INCLUSIVE.



BOSTON :

W. J. SCHOFIELD, PRINTER, 105 SUMMER STREET.

1891.

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NOTICE.

The SOCIETY OF ARTS, established in conformity with the plan of the Massachusetts Institute of Technology, as set forth in the act of incorporation, April, 1861, held its first meeting on April 8, 1862.

The objects of the Society are to awaken and maintain an active interest in the practical sciences, and to aid generally in their advancement in connection with arts, agriculture, manufactures, and commerce.

Regular meetings are held semi-monthly from October to May, inclusive, in the Institute Building; and at each meeting communications are presented on some subjects germane to the objects of the Society, as stated above.

The present volume contains the abstracts of the communications made during the year ending October 1, 1891, most of the business portions of the records being omitted.

The thanks of the Society are due to Mr. Easton Devonshire for the loan of the electrotpe used in illustrating his paper on "The Purification of Water by Metallic Iron," and to Mr. A. E. Hunt for those illustrating his paper on "Aluminum."

For the opinions advanced by any of the speakers the Society assumes no responsibility.

LINUS FAUNCE,
SECRETARY.

BOSTON, SEPT., 1891.

PROCEEDINGS OF THE SOCIETY OF ARTS

FOR THE TWENTY-NINTH YEAR.

MEETING 405.

Crenothrix Kühniana.

BY PROF. WILLIAM T. SEDGWICK.

The 405th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, October 9, 1890, at 8. P.M., Prof. G. F. Swain in the chair.

After the reading of the records of the previous meeting, and the election of new members, the chairman introduced Prof. W. T. Sedgwick, of the Institute, who read a paper on "*Crenothrix Kühniana*."

Prof. SEDGWICK said: The object of filtration is purification. This, partial or complete, is also ordinarily the result of filtration, whether it be effected through longer or shorter reaches of soil, as in the natural filtration of the ground waters into wells or springs, or through artificial sand filters worked either intermittently or continuously. There are some cases on record, however, in which the filtrate, or effluent, thus obtained, instead of issuing pure and clear, and remaining so, has speedily become contaminated with an unsightly and sometimes ill-smelling vegetation of an unusual form and highly peculiar character, namely, a luxuriant growth of the "*Well-thread*," *Crenothrix Kühniana* (Rab.), Zopf. A recent attack of this singular plant in the water service of Rotterdam, in Holland, and its presence in certain water supplies of Europe and America, serve to make it of special interest at the present time, particularly to those engaged in the study of the principles of filtration. *Crenothrix* is interesting to the biologist also. Its striking habit of depositing the oxide of iron in its highly developed sheaths, and especially its vital dependence

upon certain salts of iron; its size, perhaps the largest, among the bacteria, the smallest of living things; its faculty of leaving its out-grown shell, or sheath, after the latter has become a hindrance; the history of its shifting fortunes for a recognized place among the lower fungi; its absence from water perfectly purified, and its occurrence in water imperfectly purified, by filtration;—all of these tend to surround *Crenothrix* with peculiarities which excite the interest of the investigator.

The immediate cause of the present paper is a recent Report upon this and other organisms living in the under-ground portions of the Rotterdam Water Works,—a report published by Prof. H. De Vries of Amsterdam, the well known botanist, who has directed a biological investigation, ordered by the authorities of Rotterdam, into the causes of an appearance of *Crenothrix* in the drinking water of that city. But quite apart from this recent attack, *Crenothrix* deserves close attention for what it has done, and is still doing, elsewhere. Moreover, it is more than likely that the success or failure of the continuous filtration of drinking water may largely depend upon our ability to forestall the development of *Crenothrix* in the effluent. In any event, we shall do well to bring together the facts that we have already at hand concerning *Crenothrix*, inasmuch as these are widely scattered, and accessible only to specialists.

Since Ehrenberg, the first biologist to bring the achromatic objective to bear upon the micro-organisms, botanists have observed in various natural waters brownish thread-like vegetable forms of extremely simple structure. New genera and species were speedily formed to receive them, and even previous to 1850 two of these genera were well recognized and known as *Leptothrix* and *Hypheothrix*. The former was then described by Kützing as consisting of *very slender filaments, free, without branches and without sheaths*, the latter of *filaments, unbranched, but covered with sheaths*.

Our plant appears to have been first observed by Prof. Julius Kühn in 1852, in a drain pipe leading from the reservoir of a garden in the vicinity of Bunzlau (Silesia), and was soon after named by Rabenhorst in his honor *Leptothrix Kühniana*. Under this title it appeared in Rabenhorst's "Algæ of Saxony and Central Europe." In 1865, however, Rabenhorst briefly described it, in his "Fresh-water Algæ," as *Hypheothrix Kühniana*, as follows: "*Hypheothrix Kühni-*

ana (*Leptothrix Kühniana*, Rabenhorst). Scattered Hypheothrix, interwoven either closely or loosely, contaminated and colored with the oxide of iron. Trichomes (filaments) slightly curved; palely æruginous; indistinctly articulated; in places interrupted; having thick sheaths, folded and colorless. Diameter of the filaments 0.0001–0.00012". Habitat, in drain pipes. First discovered by J. Kühn."¹

In March, 1870, Prof. Ferdinand Cohn, of Breslau, received for microscopical examination samples of water from a well located in a district of the city notorious for typhoid fever. Aside from a not uncommon turbidity, these waters contained small brownish yellow masses floating about in considerable numbers in flocks from one to two millimeters in size. After some time these settled to the bottom and formed themselves into larger flocks, which were found to be composed of the colorless filaments of an alga. The examination of fresh samples of water from the same well, and of samples from other wells in and about Breslau, revealed the presence of the same organism, so that Cohn was convinced that it was "a form very widely represented in well waters." Moreover, since it appeared to belong to an entirely new genus and species, Cohn proposed to call it the *Brunnenfaden*, i. e., the "Well-thread," and, turning this into more technical language, he proposed to establish for it a new genus, *Crenothrix*. Finally, Cohn made a thorough study of the life history of *Crenothrix*, and, finding but one kind, in which there was also an abundant and peculiar spore formation, he proposed for it the specific name of *polyspora*. These facts, and many more, are recorded in his well-known paper on *Crenothrix*.²

In 1878 there appeared in the Tegel water supply of Berlin, Germany, a serious contamination in the shape of a flocculent yellowish-brown substance, which, when the water was allowed to stand, settled to the bottom of the vessel containing it. The investigation of this contamination was referred by the government of the city, through Prof. Virchow, to Prof. Oskar Brefeld and Dr. W. Zopf, whose reports³ form an important contribution to our knowledge of

¹ Rabenhorst, *Flora Europæa Algarum Aquæ dulcis*, etc., Bd. II. p. 88, Leipzig, 1865.

² F. Cohn, Ueber den Brunnenfaden (*Crenothrix polyspora*), etc. Beiträge zur Biologie, Bd. I. pp. 117–131.

³ O. Brefeld und W. Zopf, Bericht an den Hohen Magistrat der Stadt Berlin über die von ihnen angeführten Untersuchungen des Tegeler Wassers, Berlin, 1879. W. Zopf, Entwicklungsgeschichtliche Untersuchung der *Crenothrix polyspora*, Die Ursache der Berliner Wassercalamität, Berlin, 1879.

Crenothrix, and are especially interesting as a study of the first "water calamity" of magnitude in which the evil was definitively traced to this organism as a cause. Examination soon revealed the fact that the yellowish-brown flocculent masses were composed chiefly of Crenothrix. This was especially abundant in the reservoir, though present in the water of all the wells from which the supply was derived, as well as in the service pipes in the city itself. The report was summed up as follows: "The principal part of the contamination is Crenothrix, which lives in the water as its natural soil, and, by means of invisible germs, is able to develop and multiply, thus producing visible masses." The water of the lake (Tegel) itself, from the surface and from various depths, was free from Crenothrix, as was also the superficial layer of the lake bottom; but in numerous wells in Berlin and elsewhere, in the reservoir at Charlottenburg and in other water works, as well as in unfiltered water from the river Spree, it was found in more or less abundance. Examinations of the soil showed that "the distribution of Crenothrix in the ground is not merely superficial; on the contrary, its germs are to be found in water taken from the most various depths." Accordingly, the conclusion was drawn that "there is no reason to suppose that water drawn from a considerable depth would remain free from this contamination, since the germs of Crenothrix, which inevitably have access to such water, must, in all probability, develop in such wells, reservoirs, or pipes its characteristic flocculent vegetation." Inasmuch as it appeared to be completely removed by filtration, it was, however, concluded that "a degree of clearness and purity which constitutes an effectual removal of the contamination" can be thus obtained.

- In the course of his microscopical examinations — chemical analyses unfortunately are wanting — Zopf detected Crenothrix in the water supply of Halle, and this organism was in turn identified by Prof. Kühn of Halle as the same which he had originally discovered in drain pipes at Gnadeborg, near Bunzlau, in 1852. This identification was further confirmed by comparison of the *Crenothrix polyspora* from Berlin and Halle with dried specimens of *Hypheothrix* (*Leptothrix*) *Kühniana* of Rabenhorst. Accordingly, in his paper upon Crenothrix (*op. cit.*), Zopf suggests that in future this plant be known as *Crenothrix Kühniana*, Rabenhorst. This name, together with that of Zopf, who, as stated, has identified *Crenothrix* with *Hypheothrix*

Kühniana, Rab., is adopted by the editors of the latest edition of Rabenhorst's "Kryptogamen-Flora," in which it is described provisionally under the genus *Crenothrix*, Cohn, as *Crenothrix Kühniana* (Rabenhorst). Zopf.¹ It is also believed by Cohn and by Zopf that Radlkoper's *Palmellina flocculosa*, detected in certain wells in Munich (Zeit. für Biologie, Bd. I.), is a special form of the same plant.

In 1879 Zopf found that *Crenothrix* had been reported only in a single German province, namely, Silesia. Kühn, Cohn, and Kirchner had reported it in that province alone, and only from drains, wells, and springs. Brefeld and Zopf found it abundant also in Brandenburg and in Saxony. Prof. Kühn found so much of it in the Halle water service that he recommended resort to new wells in a different locality as a source of the public supply. From these and other considerations, Zopf was led to suspect that *Crenothrix* would be found eventually to be much more common than had been supposed hitherto. To this opinion he was led not only by the fact of its abundance in ground waters as far apart as those of Breslau, Berlin, and Halle, but also because of his discovery of *Crenothrix* in the unfiltered surface water of the river Spree. Zopf's suspicion of the wide distribution of this organism has been fully justified. It is now so well known and so much dreaded in Europe that De Vries, in his recent paper, has called it "the pest of water works."

In the United States *Crenothrix* is probably also common. It is only recently, however, that its presence has been widely recognized, and Wolle, in his "Fresh-water Algæ of the United States," published in 1887, refers to it as follows (p. 294): "We are not aware that the plant was recognized in this country until recently, 1886. It was found in somewhat limited quantity near the inlet to Lake Chatauqua, New York, whence part of the water supply to the city of Jamestown, N. Y., is taken." It appears to have been brought to his notice for the first time by Mr. George W. Rafter, who had detected it in abundance in the water supply of Jamestown, in 1886.² It was also observed by Mr. G. H. Parker, Biologist to the State Board of Health of Massachusetts, in 1887, in the water supplies of Brookline, Watertown, and other places in Massachusetts, and it is now known

¹ Kryptogamen-Flora, 2te Auflage, Bd. I. p. 67, Leipzig, 1884.

² G. W. Rafter, On the Fresh-water Algæ, and their Relation to the Purity of Public Water Supplies. Trans. Am. Soc. Civil Engineers, Vol. XXI. p. 497, December, 1889.

to occur commonly throughout the State.¹ In some cases it causes great annoyance (as, for example, in the Wayland water supply), while in other cases (as, for instance, in the Brookline supply), although it is present in small quantities, it does not appear to be noticed by the consumers of the water.

From the facts already reported it is clear that *Crenothrix* has usually appeared in ground waters, although it was detected by Zopf in the river Spree. Brefeld and Zopf also conclude that it is able to live in the earth itself, and is actually present in the ground even to a great depth (60 feet). So far as I am aware, there is no case on record in which *Crenothrix* has given trouble in any purely surface water supply. It was found by Kühn in drains: "I have found the plant in drain pipes in great quantities. It can, by itself alone, choke up drain pipes if these are too small in caliber in proportion to the volume of water. Drain pipes which run full for a long time are in danger of being choked by this plant if the quality of the water favors its development."² It was detected by Cohn in wells and springs; by Zopf in wells, reservoirs of well water, and in one case in a river, but was absent from the Tegel Lake and from filtered Spree (river) water. It was discovered by Rafter in the Jamestown, N. Y., supply, which is derived partly from wells and partly from Chataqua Lake through a conduit. This conduit is about two miles long, passes through a swampy region, and is probably not perfectly tight, as it is said to have been "loosely constructed." Its occurrence in Massachusetts is usually in water derived from wells or "filtering galleries," as, for example, in Brookline, Watertown, and Wayland.

In all of these cases we are obviously dealing with filtered water, since the waters of springs and wells are usually only surface waters naturally filtered. As stated above, however, Brefeld and Zopf were led to believe that filtration offers "an effectual removal of the contamination." This is probably true, so far as a removal of the unsightly flocculent masses is concerned. But inasmuch as the source of *Crenothrix* appears to be somehow or other connected with filtration, as is indicated by its almost exclusive occurrence in great quantities, in ground (i. e., in filtered) waters, it is likely that this remedy

¹ Nineteenth Annual Report, State Board of Health of Massachusetts, pp. 83-84, Boston. 1886.

² Quoted by Zopf, from a letter written to him by Prof. Kühn. Zopf, *op. cit.*, p. 18.

would be in some cases merely a temporary one, particularly as the germs of *Crenothrix* are small enough to pass through many filtering materials. On the other hand, it is not unreasonable to suppose that the filtration of a surface water free from *Crenothrix* — inasmuch as by this operation such a water is virtually converted, more or less completely, into a ground water — may, in a certain number of cases, so alter the original composition of the water that it can support a luxuriant vegetation of *Crenothrix*. It appears, moreover, that this condition, with disastrous consequences, has in fact already occurred in some cases; and since this involves an unforeseen obstacle in the theory and practice of sand filtration upon a large scale, it cannot be too carefully considered.

The most noteworthy case of this kind is that already referred to as having occurred in Rotterdam, Holland, in 1887, and later. It is fully reported in an admirable paper by Hugo De Vries, Professor of Botany in the University of Amsterdam.¹ What immediately follows is taken almost literally from De Vries's Report.

The Water Works of Rotterdam draw their water from the Maas, and clarify it by means of sand filtration after most of the sediment of the river has settled on standing.

Since their establishment, in 1874, these works have furnished a clear and sufficiently satisfactory water, until suddenly, in the spring of 1887, the so much dreaded *Crenothrix Kühniana* appeared in great quantities. This unfortunate phenomenon coincided with a considerable enlargement of the whole service. In 1886 thirteen new filters were made ready and put into use, having sixteen thousand square meters of surface, while at the same time the eight old ones, having an area of eight thousand square meters, were disconnected.

The building of a new engine-house was in progress, but the new reservoir for filtered water was not yet ready, and the filtered water from the new filters had meantime to be conducted through the old conduits and the old reservoir to the old pumps. This extensive enlargement of the establishment was a consequence of the annually increasing consumption of water in the city. The original establishment (1874) was based on an estimate of a daily consumption of at

¹ H. De Vries, Die Pflanzen und Thiere in den dunkeln Räumen der Rotterdamer Wasserleitung. Bericht über die Biologischen Untersuchungen der *Crenothrix*-Commission zu Rotterdam, vom Jahre 1887, pp. 1-55, Jena, 1890.

most five thousand cubic meters. In 1887 the daily consumption had reached a maximum of forty-three thousand cubic meters, and in 1889 of about fifty thousand. For several years previous the management had labored under an excessive demand, which neither allowed the river water the requisite time for depositing its sediment sufficiently, nor permitted the basins and conduits to be cleaned properly from time to time. The attack of *Crenothrix* referred to above was as unexpected as it was sudden and severe, and the behavior of this bacterium in the water supplies of other cities aroused the fear that it would soon attain a far greater development, and would affect the purity of the water.

In order to avoid this danger, as far as possible, in the summer of the same year in which the *Crenothrix* had appeared in a threatening manner, a Commission was appointed by the city authorities, and requested to investigate scientifically the cause of the phenomenon, and, if possible, to recommend methods which should prevent an increase of the evil, and finally secure complete immunity from it. This Commission worked under circumstances which facilitated to an unusual degree a thorough scientific study of the problem. The impossibility referred to of cleaning all basins and conduits in a suitable manner had allowed the vegetation in them to develop to an extent seldom witnessed by investigators. At the same time, the new filters and conduits lately put into operation served for comparison.

After the work of the Commission in the winter of 1887 and 1888 had been finished, several questions still remained whose solution was desired for the completeness of the study. The continuation of the works on the new building, and especially the cleaning of the old basins and conduits, in 1889, afforded this opportunity.

For the microscopical investigations, which were conducted by Prof. De Vries and Dr. Dupont, a little laboratory was fitted up in the water tower which supports the high reservoir, and in the basement of which is the reservoir of unfiltered water. This laboratory enabled them to investigate at once, for the most part, the samples taken from the basins and canals, and to observe the remarkable plant and animal life of the under-ground conduits, etc. in full activity.

After these introductory observations De Vries divides that portion of his report which deals with *Crenothrix* into seven sections, which well illustrate the scope of his paper, as follows:—

1. *Crenothrix Kühniana*, the Pest of Water Works.
2. The Appearance of *Crenothrix* in the City Water Works in 1887.
3. The Vegetation in the Maas and in the Open Basins (of Unfiltered Water).
4. Investigation of the covered Conduits of Unfiltered Water.
5. Biological Considerations concerning the Life in dark Reservoirs.
6. *Crenothrix* in the Reservoirs of Filtered Water.
7. The Danger of Contamination of the Water before Filtration.

The first section affords a convenient summary of our knowledge of the life history of *Crenothrix* as worked out by Cohn, Zopf, and, for a closely related form, still more recently by Winogradsky.¹ It will be observed that *Crenothrix* is no longer considered to be an alga, but, instead, a fungus (*Schizomycete*), or one of the bacteria. Besides, it is included by Winogradsky as one among several giant bacteria which agree in a peculiar habit of acquiring incrustations of ferric oxide in or upon their sheaths. This habit of *Crenothrix* and other forms was observed many years ago; and Zopf was led to believe that the existence of the plant is absolutely dependent upon the presence of certain salts of iron. In this he has been confirmed by Winogradsky, whose designation of such forms as the "iron bacteria" is certainly convenient.

De Vries continues as follows:—

The iron bacteria are the largest forms in the whole group of bacteria. Although their cells are invisible to the naked eye, they are so united, end to end, as to form threads, or filaments, which in turn tend to make "flocks," or masses visible to the naked eye, often a millimeter and sometimes a centimeter or more in size.

A good hand lens reveals the structure of the flocks very clearly, but for a complete recognition of the character of the organisms a microscopical examination is required. This shows that the cells composing the filaments have, for the most part, a cylindrical form. The whole filament is enveloped by a sheath which is at first thin, but gradually increases in thickness. The most striking and the most characteristic property of the iron bacteria is their power of depositing in this sheath the oxide of iron (ferric oxide). Entirely

¹ S. Winogradsky, Ueber Eisenbacterien. *Botanische Zeitung*, Bd. XLVI. (1898), p. 260.

colorless and transparent at first, they gradually become pale yellow, and then darker, until finally they are deep brown. At the same time their consistency is altered. They are at first flexible and soft, but gradually become hard and brittle. The thick, hard, dark brown sheaths are then no longer adapted to the life of the enclosed cells, and sooner or later are abandoned by them. The cells push themselves in single file out of the end of the sheath, or sometimes, partly sidewise, through chinks in the sheath. In the latter case, the thread appears to branch; in the former, the escaped bacteria continue the old sheath, and the new parts speedily undergo the same transformation as the old, whereupon these also are in their turn forsaken. In this way long and occasionally branched sheaths are formed by a comparatively few cells, and the older, lower cells in the filaments composing the flocks are thus found lifeless and empty, with only their tips still living. A comparatively slow increase of the bacteria may thus be accompanied by a relatively large sheath formation.

These organisms form their ferric oxide from the dissolved iron salts of the water, and especially from the most widely distributed of these compounds, the ferrous carbonate. Without soluble ferrous salts, their life cannot long continue. They thrive best in those waters which contain iron rust in the presence of organic matter, since in such waters the formation of ferrous carbonate is incessant. In all probability, the oxidation of the ferrous to the ferric oxide forms an important part of the vital processes of these cells, and the brown substance deposited in the sheaths is to be regarded not as the refined product, but as the dross of the operation. In colorless sheaths which had been abandoned, in spots, by their cells, Winogradsky observed that the yellow coloration occurred only where the cells lay. Around the empty spots the sheath contained no ferric oxide. Equally ineffective are empty sheaths, or such as contain only dead cells.

Soluble ferrous salts form, therefore, an indispensable condition for the welfare of these organisms. In other respects, however, they are very easily satisfied. They are nourished partly by the ordinary salts dissolved in water, and partly by dissolved organic substances which originate in the putrefaction of vegetable and animal remains. On the other hand, traces of such compounds appear to suffice for them. Winogradsky cultivated them in a water to which only 0.005 to 0.01 per cent of calcium butyrate or sodium acetate had been added.

Fortunately, the normal content of our drinking waters in organic matters is insufficient for their support; and when such waters have been freed by filtration from all suspended and decomposing particles, they no longer form a suitable nutritive medium for these, the so much dreaded enemies of water works. Most natural waters, however, before filtration, are more or less favorable for the support of these organisms.

Among the iron bacteria, *Crenothrix Kühniana*, or *Crenothrix polyspora*, the only species of the genus, is the commonest and the most important form found in water works. It appears to be a plant widely distributed throughout the world, growing chiefly or by preference in drain pipes, deep wells, and other badly lighted water chambers. It is due to its power of extraordinarily rapid increase that it often covers, in a few months after the introduction of its germs, or after the conditions for its nourishment have become favorable, the entire walls of the reservoir, of the drain pipes or conduits, with a felt as thick as a finger, of which single portions are soon sufficiently developed to be swept along with every current as brown or blackish flocks. In this way it comes to pass that it is a real calamity in water works, making the water disagreeable for domestic use, and entirely unfit for many industrial purposes.

In order to comprehend more fully how such a sudden increase takes place, we must consider somewhat more closely the structure and the development of *Crenothrix*. Both have been extensively and thoroughly studied by Dr. W. Zopf, when the plant for the first time appeared in alarming quantities in a water supply. This was the case, as is well known in Berlin, in 1878.

The first method of multiplication depends upon the capacity of all the cells composing a filament, if they become isolated in any way, to develop each a new filament. When, for instance, the cells free themselves from their old rust sheath, and, before they form a new envelope, are broken apart by the current or by a blow, obviously we have supplied the germ for one or several flocks. But besides this the plant possesses other methods of multiplication. In the thicker filaments the cells divide not merely transversely, as in the thinner threads, but also lengthwise. Thereupon each cell divides into two or four adjoining cells. These latter separate and form the so-called microspores. In a filament in which this process has occurred, as

soon as the cells have left their sheath in the usual manner, these microspores escape as innumerable entirely distinct masses, which speedily become scattered in the water. Each microspore, immediately after its escape, begins to divide. Division takes place in all directions, and a little cluster soon arises, composed of hundreds of cells. The sheath with which each cell envelopes itself changes in this case into a "slime" or jelly, which, however, becomes colored in the usual manner with the oxide of iron. By means of this "slime" the whole mass is stuck or pasted to any part of the walls of the reservoir, or to any objects within it. After some time the course of development changes, and each cell of the cluster grows out into a filament. In some of these the cells divide transversely only, and form the so-called macrospores; in others the above described microspores arise.

The slime clusters, after they have developed into bundles of filaments, are the well known "flocks" of *Crenothrix*. These latter arise, however, more quickly in other ways far more favorable for their dislodgment. This occurs, first, when the microspores do not leave their sheath early enough, or when in this process some of the spores are left behind in the sheath. They then germinate inside the latter, and each, growing out into a filament, bursts through the old envelope. A whole bundle of such new threads can thus be connected, at their point of origin, by the old sheath. Secondly, there is often observed an apparent branching in such a way that innumerable cells have stuck fast upon an old sheath, and there germinated. Flocks of this sort formed the bulk of this contamination in the Rotterdam Water Works. This sort of branching may be repeated so often that many flocks reach the size of a centimeter or more, as already stated. It is obvious that such masses may easily be broken off from their brittle stalks,—the old dead sheaths,—and so join the current of water.

Every cell may, therefore, by successive divisions, develop a new flock. If foods are present in sufficient quantity, the divisions follow one another rapidly. Moreover, each little filament forms, again and again, new sheaths. From the most insignificant beginnings, a very extensive contamination of the water may thus occur within a short time. If we reflect, furthermore, how dilute are the solutions from which this plant is able to manufacture its foods, and that it lives

quite as well in total darkness as in the daylight, it becomes clear that by all its peculiarities it is stamped as a veritable pest of water works.

The foregoing summary of the life history of *Crenothrix* by De Vries is based upon the observations of Cohn, Zopf, and Winogradsky. Winter, in his systematic treatment of the Fungi,¹ places *Crenothrix* provisionally at the end of the Schizomycetes, and gives the following brief characteristics of the genus:—

“*Crenothrix*, Cohn. Filaments cylindrical, transversely divided into cells, slightly thickened and club-shaped above, sheathed. Increase takes place through the cells of which the filament is composed, which escape from the sheath and develop into new filaments. Reproduction by spores which are formed within the sheath through further division of the cells of the filaments. The spores either grow out into filaments directly, or through continued division form gelatinous colonies which later develop the filaments.”

The species is characterized by Winter as follows:—

“*Crenothrix Kühniana* (Rabh.), ZOPF. Filaments occurring in whitish or brownish tufts, $1\frac{1}{2}$ –5 μ thick, at the end widened to 6–9 μ ; cells of the filaments of very unequal length. Spores 1–6 μ in diameter. In wells, drains, etc.

“An often very troublesome fungus, since it contaminates water and chokes small pipes. The cylindrical filaments, slightly thickened and club-shaped above, are distinctly divided transversely into cells; these afterward separate from one another, but even in that case soon become enveloped in a sheath which, colorless at the start, becomes yellow or yellow-brown through the deposit of iron. The sheaths, at first closed, are eventually burst open by the growing cells within, which pass out. Every individual cell can develop a new filament. In other cases the filament remains enclosed in its sheath; its cells subdivide into short disks, which by vertical divisions break up into small ball-shaped cells. These may be considered to be the spores of the organism. Even within the sheaths they often develop into new filaments, which penetrate the jelly-like swollen sheath, or they may leave the sheath and develop entirely without it; either growing out into filaments, or by continued division forming larger or smaller colonies of roundish cells, which are held together by the gelatinized membrane. These colonies are known as the *Palmella* form [*Zoëglæa*,

¹ Rabenhorst's Kryptogamen-Flora, loc. cit.

Cohn], and are probably equivalent to *Palmellina flocculosa*, Radlkofer. Each of these cells, again, is able to form a new filament."

In the spring of 1882 there suddenly appeared in the water supply of Lille, in France, a pollution so extensive that the water for a time could not be used. For some years previous the water had occasioned anxiety on account of its reddish color, bad taste, and disagreeable odor, but it had not produced serious trouble until April, 1882. At that time it became so bad that in certain quarters of the city it could not be used, and for some time afterward every heavy rain was followed by a fresh disturbance. The water bore a rusty scum, easily strained out. Ferruginous deposits also formed in the reservoirs and some of the distributing mains. The water became so bad that even the tram-horses at one time refused to drink it. This attack of *Crenothrix* was studied by A. Giard,¹ who found little to add to the work of Zopf, except that the microgonidia appeared to him to be motile, and furnished at one time with a flagellum. These afterward pass into an irregular *Merismopædia* stage, and still later into zoöglæa. From the zoöglæa the usual filaments are finally produced. The source of the drinking water of Lille appears to have been a series of wells in a marshy region, and the conditions appeared to Giard similar to those that prevailed in the original Tegel supply of Berlin. He therefore urged sand filtration as a remedy, and advised towns about to institute water supplies to avoid ground waters as a source of supply.

MEETING 406.

Electric Welding Applied to the Manufacture of Projectiles.

BY LIEUT. W. M. WOOD.

The 406th meeting of the SOCIETY OF ARTS was held at the Institute, on Thursday, October 23rd, at 8 P. M., Col. E. H. Hewins in the Chair.

After the reading of the records and the election of new members, the chairman introduced Lieut. W. M. Wood, of the Thomson

¹ A. Giard, *Comptes Rendus*, 1882, p. 247.

Electric Welding Company, who read a paper on "Electric Welding Applied to the Manufacture of Projectiles."

Lieut. WOOD said: I am asked tonight to tell you something of a new process which has been originated and developed within the past year,—a new and important application of an art in itself new,—electric welding.

At this moment, when there is so general an interest manifested throughout the country in the question of the nation's arms and defences, this new invention, which bids fair to supersede and immensely cheapen existing methods, is sure to claim its share of attention, both from experts in ordnance and the general public.

Before entering upon the subject proper, I wish to say a few words upon the general state of military art and on the production of projectiles in particular. For nearly a generation we have stood aside and watched others pass us in the race, forgetting what we knew so well at the close of our late war, until now we have finally awakened to find ourselves relegated to almost the lowest place among the nations of the earth. To use a lowly simile, we might have been, until very recently, likened to a crab which had just shed its shell,—rich and fat, but helpless; unable to assert our rights or aid our friends in time of need.

Since the earliest times, man's ingenuity has been taxed, first to improve his weapons, next his defences. The race between projectiles and armor commenced with the bow and arrow or sling, as against the rawhide-covered buckler. It has passed by gradual evolution through an infinite number of stages; sometimes the armor, sometimes the projectile ahead; generally the latter. Indeed, at times, the projectile has been so much ahead as to cause the total abandonment of armor. This happened when the bullets and slugs from the crude blunderbuss of the Middle Ages made the matchless armor of the warrior of the day worse than useless. Some authorities are inclined to believe that an analogous case exists now and that on the sea, at least, it is folly to burden vessels with an enormous weight of armor, which can be pierced so easily by the heavy projectiles thrown by the enormous high-powered guns in use. To the casual observer this may seem true, but on the other hand we must not forget that armor *does* protect against the great number of moderate-sized projectiles, and that if you can even only partially protect the vitals of your

structure, it is much gained. We must also remember that these latest developments of armor and projectile have never been pitted against each other in actual warfare and that there will be a vast difference between firing through a target at point-blank range and at a swiftly moving, rolling, wavering object a mile or more away, which is at the same time firing back at you.

At the present moment, it looks as though the projectile was about to gain another point over armor and become a still more important factor. Artillerists on shore are now directing their attention largely to the use of breech-loading rifled howitzers or mortars. These guns are fired at a great elevation, rarely less than 45° and frequently at 60° . The projectile has consequently a high-curved trajectory, and plunges down on and through the decks of vessels or behind parapets. The decks of men-of-war are frequently not protected at all except over the engines, boilers, and magazines, where a curved armored deck is used with a maximum thickness of from 4" to 6"; 4" is the greatest thickness of the curved protective decks of our new cruisers, and is the only armor those now afloat have.

The varying ranges of these howitzer-thrown projectiles are given by increasing or decreasing the weight of the powder charge.

In some recent experiments made by Krupp in Germany very satisfactory results have been obtained by projectiles thrown from this class of gun against horizontal targets representing the armored decks of ships.

The defences of Boston and our other seaboard cities are to comprise a large number of guns of this class. They fire both armor-piercing and common shell. Redoubts and turrets on shore can be armored as heavily as you please, or guns and troops can be defended by that most excellent protection, the earthwork. Afloat, however, where every pound carried is a matter of serious consideration, the problem is a very different one, and the weight of armor must necessarily be limited by the size of the vessel. A proper navy, however, will always be made up of a number of vessels of various kinds, more or less dependent on each other, from the gigantic battle ship, fully protected by the heaviest armor, down, including the partially protected cruisers, fast unprotected vessels, despatch boats, converted merchantmen used as commerce destroyers or transports, torpedo boats, etc.

Troops in the field are like the unarmored cruisers, torpedo boats, and converted merchantmen, practically unprotected.

For use against these various defences and where there are no defences, except distance and advantage of position, there are in use three general classes of projectiles (not considering the more or less experimental dynamite and other highly explosive shells). They are, first, the armor-piercing shell, used solely, as its name indicates, against heavy armor; second, common shell, used against unprotected vessels and troops, for bombarding cities and earthworks, for target practice, etc.; third, shrapnel, so named from its inventor, extensively used in field operations on shore against bodies of troops, and at sea against open boats, torpedo boats, or any unprotected body of men.

Leaving the ordinary bullet of the shoulder rifle out of the question, these projectiles range in weight from those of a single pound to the gigantic missiles of the 110-ton gun, which weigh about one ton and are driven by almost a half a ton of powder.

Now, in order to show how much is gained in the construction of projectiles by the Thomson electric-welding process, I will briefly describe the present methods of manufacture.

First, the armor-piercing shell. To fulfill the Government requirements these must be made of a fine quality of steel, capable of being made very hard, and still be tough. In the first operation it is forged or rolled into a rough, solid plank. After this it is placed in a lathe and turned off accurately on the outside, and the powder chamber bored in the axis of the shell from the base, as in this specimen. This opening is then closed by a carefully fitted screw plug, in the center of which is a smaller threaded hole, into which fits the percussion fuse, which explodes the shell on impact. A groove is now turned in the outside near the base and knurled or roughened. This is for the copper rotating band, and the roughening is to prevent its slipping when the copper enters the rifling of the gun. Next the shell is hardened by one of the various processes, which are more or less satisfactory; and, finally, the copper band is forced into place by hammering or hydraulic pressure, and turned off true to gauge. This completes the projectile, and you will readily understand that all of this work is slow, tedious, and expensive. Anyone who is familiar with the operation of machining high carbon or tool steel will appreciate this. As a matter of fact, a 6" armor-piercing shell which

only weighs ninety-four pounds costs in the neighborhood of \$65 or \$70.

Next come common shell. These, at present, are cast either of steel or iron, but even in this cheap form of production many difficulties are met with. In the first place, the shell usually has but one small opening to the inside powder chamber, and this only allows the use of a single "print" to hold up the core which forms the interior cavity; consequently, when the molten metal flows in, it pushes this core out of place, and, the resultant casting is eccentric,—thin on one side, thick on the other; frequently so much so as to cause it to be discarded entirely. When the castings are received from the foundry, they are first carefully calipered on the inside by a skilled operator who uses a delicate instrument called a "star gauge," which expands within and enables him to determine the amount the casting is out of true, which he marks on the shell. It is then passed to the hands of the machinist. He is obliged to place it in his lathe eccentrically, so that the outside will be turned true with the inside; and you can imagine that even after all this care they are never perfectly concentric. Another serious difficulty met with in the cast projectiles is the liability to small blow holes or porosity, which, though they sometimes escape detection, always cause the rejection of the projectile when discovered. Through these holes the gases of the charge might be driven, and thus cause a premature explosion of the shell in the gun. Steel shell of this description of six-caliber cost about thirty dollars each. Like the armor-piercing shell, they are fitted with rotating bands and fuses, but are not hardened.

Now we come to the shrapnel. It was originally invented for use in the smooth-bore guns of the past, and was then a hollow sphere filled with small bullets, around which was poured melted sulphur as a matrix. A small powder chamber for a bursting charge was left in the middle. It was provided with a time fuse which could be set so that the shell would explode at the desired moment in its flight, scattering its contents and fragments in the face of the enemy. So far there seems to have been no very satisfactory shrapnel made for rifle guns. The difficulty is that the head or base has to be screwed on after the body of the shell has been filled with the bullets and matrix. This construction weakens the projectile very much at this point, and the head or base is apt to blow out without bursting the

body of the shell or scattering the bullets, especially as the walls of the projectile have to be made thick enough to stand the threading.

Hoping I have now made clear the general state of the art, I will explain wherein this new process differs, and will endeavor to illustrate it by the specimens I have here.

First, instead of the solid, rough-forged ingot, we have these three component parts, which when welded together will form a six-pound armor-piercing shell. Each piece is now finished to exact size, except that there is a little extra length to allow for the take-up in welding. The head and base pieces are forged in dies to shape; the central portion is simply a piece cut from a length of solid, drawn-steel piping. It has all the additional strength due to the fibrous skin inside and out caused by the drawing process. To join these three pieces, they are clamped into a form of electric welding machine designed for the purpose, and in less than a minute are joined together and made a homogeneous mass like this.

It only now remains to grind off the two burrs which you see in this specimen and cut in the groove for the rotating band. The front one of these burrs may be used to form an enlargement used in many forms of projectiles, called technically a bourillet. It supports the front portion of the shell in the bore of the gun, the remainder not touching, except at the rotating band. The other burr may be removed at the same time the rotating band groove is cut. The fuse hole has already been cut and threaded in the base piece. The shell is now ready for the hardening process. I wish to call attention here to the fact that the burrs are allowed to remain on the inside, and thus form strengthening ribs which help materially to support the shell against the great crushing strain it receives on impact. You will see that we have thus formed a stronger and better shell with a minimum of labor on the individual parts, and a few seconds work to join them together.

In order to illustrate the wonderful strength that may be gained by this welding process, I have here a shell which was constructed exactly as I have shown. It was fired through a 3" plate of iron at the naval proving grounds at Annapolis recently. You will see that it has not changed its shape in the slightest degree, nor has it even lost the copper rotating band which was carried through the hole with it. Here is another which shows a still more remarkable result.

This projectile was fired against heavy steel armor which has a resistance of about seventy-five per cent more than iron, and which was much heavier than a projectile of this size could be expected to perforate. It, however, penetrated 5", and then, owing to the elasticity of the oak backing of the plate, was thrown back about eighty feet as perfect in condition as before it was fired from the gun. The experience of the Welding Company has been that the metal seems to be strengthened at the point of welding, and this certainly seems to justify the supposition.

After accomplishing results like this, you will see that the manufacture of the common shell becomes a very simple matter. By the welding process it is quite feasible not only to join iron to high carbon steel, but to weld wrought iron or steel to steel castings, or even to cast iron. Hence, in this case, it is only necessary to substitute common iron or low carbon steel tubing and stamped or cast heads and bases, and perform the welding operation. The shell which is thus cheaply put together has all the advantages of wrought and none of the disadvantages of cast metal. If made of low steel, it may even be hardened to a certain extent, and thus have more or less efficiency against thin armor.

In regard to the shrapnel, a single look at this section will show the problem and how it has been met. This is from a design for the United States Army 3.2" field piece. The head and base are steel castings, which have been heated and compressed to give them density. The body is drawn steel tubing $\frac{1}{4}$ " thick. The projectile was built as follows: first, the head was welded onto the body. Next, the brass tube which carries the flame from the fuse to the powder chamber at the base was crimped in at the upper end. The half-formed projectile was then inverted and the bullets placed within and the matrix poured about them. Next, the diaphragm which forms the front end of the powder chamber was put into position and the other end of the tube crimped in. The shell is now ready for the final weld, and you will notice that the base piece is provided with a shoulder, which, after the weld is made, will press closely upon the diaphragm and support it against the shock of the discharge. After the second weld is made, the shrapnel has an unbroken surface enclosing its deadly bullets, and, like the other shell, is ready to be fitted with rotating band and fuse.

To summarize: these shell can be produced in the method I have described, so that a wrought steel projectile can now be manufactured at less cost than a cast-iron one, which, except for target practice, is almost worthless; and as for armor-piercing shell or even molded steel shell, there can be no comparison as to cost of production. This same principle can also be applied to solving a still more difficult problem, and one which has hitherto baffled the skill of the inventor, viz., the welding the solid heads onto the large brass cartridge cases now used with the projectiles of rapid-fire guns. A rapid-fire gun is one having a non-recoil and pivoted mount. It is aimed and fired from the shoulder, like an old-fashioned swivel. They range in size up to as large as the 6" gun. The ammunition is fixed just the same as a bullet and cartridge of a shoulder rifle. At present, these brass cases are constructed with great difficulty, and at much expense, by drawing up from the solid ingot, and no one is prepared to make those of the large sizes in this country. By the Thomson process, which also welds brass and copper, this will be an easy matter, and the cost should be less than one-fourth that now paid by the Government for these they are obliged to import.

In conclusion, I will say that it is a well-known fact among ordnance experts that the breech mechanism and the principle of the construction of the present high-powered guns are entirely due to American invention, which was, however, forced out of the country by lack of appreciation, and was taken up and developed in Europe. I believe the day has come at last when our military inventors will not have to seek their encouragement entirely abroad, and I think that, in the very near future, our Government will be supplied entirely by cheap and effective projectiles of the kind I have shown you tonight.

MEETING 407.

How to Make Statistics Popular.

BY CHARLES F. PIDGIN.

The 407th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, Nov. 13th, at 8 P. M., Hon. J. A. Dresser in the chair.

After the reading of the records of the previous meeting, the chairman introduced Mr. Charles F. Pidgin, of Boston, who read a paper on "How to Make Statistics Popular."

Mr. PIDGIN began by giving a summary of the work that has been done in the line of collecting statistical material. He then said: What are our agencies for statistical assimilation? How shall this material be put in shape for the popular mind? The average citizen is too busy a man to examine all these publications for himself; and, as the editions are not large enough to supply every citizen with a copy, manifestly a large proportion of the community must obtain its statistics from the newspapers, the periodicals, or from works devoted to special subjects which present the contents of many volumes in a condensed form in one pamphlet or book.

The printing press is the most potent aid that the statistician possesses. As I have remarked, few, at the present day, care to listen to an address or lecture full of statistics. They may appeal to the eye, but rarely attract the ear. This suggests a potent method of reaching the public ear with statistics. Bring them into text form, — change the perpendicular columns of figures into horizontal lines of words, and instead of comparing one long number with another number, perhaps even longer, bring everything to the basis of percentages. If I say that out of 46,918,206 persons in the German empire 23,459,103 have blue eyes and flaxen hair I leave no impression upon my audience that they can carry away with them; but if I say that 50 per cent, or one-half of the inhabitants of the German empire, have blue eyes and flaxen hair, I have supplied them with a statistical point that should linger in their minds.

So, in the published report itself, it may be allowable to draw

conclusions, to make deductions, but they should be put in clean-cut paragraphs, or, better still, short sentences, so that the busy man may read and remember.

The newspaper can be of incalculable service in disseminating statistical information. It speaks often to large audiences; it adds to the fame of the statistician and to the education of its readers by publishing the results of statistical investigations. The newspaper editor is a busy man. Perhaps he has both ability and inclination to take a large volume of statistics and boil it down for his readers, and perhaps he has not. In either case it may be that he cannot spare the time,—the book is put one side,—and when the time is found the statistics are “old”; that is, they have been discussed by other papers, and it is now too late to write a review.

This status of affairs can be largely remedied *if what a statistical volume means* is brought into a few compact paragraphs by the statistician himself and made so conspicuous by kind of type or prominent position that the busy editor sees it and transfers it to the columns of his paper.

The preparation of abstracts by the statistician may seem to have a “cut and dried” appearance, but it must be remembered that this abstract is always given as an item of news, and not as an editorial utterance,—that is, the newspaper does not necessarily indorse the conclusions contained in the abstract.

Something is being done to popularize statistics. In the first place, I am glad to note that the Census Office gives percentages of increase or decrease with its population figures. This plan will undoubtedly be followed in the various bulletins to be issued. In addition, the Superintendent of the Census has appointed a special agent for abstracts and items. It will be his duty to supply the old channels, and discover new channels into which statistics can be advantageously sent. He will have a classified list of every newspaper and periodical in the country. He will also have a list of the writers and speakers who use statistical material in their articles or addresses. Not only will he supply to newspapers, writers, and speakers the information contained in census bulletins and reports, written into popular form in abstracts, and also in items of various lengths, but he will also endeavor to learn what special statistics or new combinations of results are desired, and, if possible, such statistics will be prepared

and sent to the parties desiring them. These abstracts and items will be printed on one side of the paper only, so as to be immediately available as copy, and between the items white spaces will be left, so that the party using them can cut them out and make them part of his article or speech. Each special agent of the census deals with his own specialty, and the bulletins and published reports will each have the distinctive treatment of the department from which it comes. It will be the duty of the special agent for abstracts and items to correlate this material,—that is, to write abstracts and items containing results drawn from the various bulletins or reports, and brought together in such a way as to show correlated results that the individual handling of bulletins or reports would not supply. These abstracts and items, honestly and scientifically prepared, and supplied free of all expense to all who may desire them, together with their appearance in the entire press of the country, will have a potent influence in educating the people to read and remember statistical results, and that is what I mean by “making statistics popular.”

I will give you a few illustrations of statistical items drawn from the latest bulletins of the census office:—

There were 175 supervisors for the United States census of 1890. New York with 6,000,000 population had eleven of this number, while Massachusetts with 2,200,000 population had but one.

There are 640 cities and towns in the United States in which the statistics of manufactures will be taken by special agents, owing to the large number of establishments therein and the great value of the product. Massachusetts with one-thirtieth of the population of the United States has 128 of these cities and towns, or one-fifth. The five other New England States have 70. New York and Pennsylvania have 99 combined.

The United States owes nine hundred and twenty-three millions of dollars. It has paid off nine hundred and ninety-nine millions since 1880, or more than one-half. It is evidently a prosperous country.

In the same ten years the different States which now owe one hundred and thirty-two millions of dollars have paid off seventy-two millions, or more than one-third, since 1880. Another sign of prosperity.

In 1889 there were 3151 miles of street railway in 56 cities in

the United States. Massachusetts, with one-thirtieth of the population, had nearly one-twelfth of the mileage. Of the 3151 miles of street railway in the United States in 1889 about 75 per cent were operated by animal power, 8 per cent by electricity, 8 per cent by cable, and 9 per cent by steam on both surface and elevated roads.

With its report for 1889, being authorized so to do by the Legislature, the Massachusetts Bureau of Statistics of Labor introduced a new plan of issuing its annual reports. Being composed of parts, each distinct in itself, these parts are issued as soon as ready in pamphlet form. A double purpose is secured by this method of publication. The statistics reach the public earlier, for Part I is not held back several months until the entire report is ready. Again, the newspapers give as much space to the consideration of one of these parts as they formerly did to the entire report. This means a gain to the bureau, the newspapers, and the public. It would seem that this plan could be advantageously followed in the publication of census volumes. Then each subject could be issued in pamphlet form as soon as ready without waiting a year or more for the complete volume. This plan would also do away with the too often cumbersome general analysis, for each part or section would necessarily be accompanied by its special analysis.

The Massachusetts Bureau of Statistics of Labor will present three statistical novelties in its reports for 1890 and 1891. The first one will be a "Labor Chronology." We read in the papers from day to day of strikes in Massachusetts, in other States of the Union, and in foreign countries. We also read of movements in the many phases of the labor question,—co-operation, building associations, new trade unions, labor legislation, the starting of new industries or the marked development of old ones, of the deaths of prominent labor reformers, the Janus-like effects of the tariff,—in fact, the daily record of industrial progress, decline or conflict. The "Labor Chronology," as its name indicates, will supply a condensed history of all such points for the year 1890, and succeeding years. Not only will the arrangement be chronological, but it will be arranged, also, by subjects, so that the editor, politician, writer, or working man can consult this chronology and find the year's history as regards strikes, co-operation, industrial partnership, growth of manufactures, labor legislation, or any other labor subject in which he may have a particular interest.

The second will be a condensation of all the statistics relating to wages, prices, and cost of living, in this and foreign countries, and the results classified as regards both wages and prices, as high, medium high, medium, medium low, or low. We can then see, at a glance, the relations of wages to prices in the countries considered, for specified years.

The third departure from routine work will be the publication of a statistical abstract of Massachusetts public documents. The public document series now numbers forty-two publications, although all do not contain statistics. Such as do, however, will have their salient points compressed into a page or less, so that the mechanic, mill operative, or manufacturer can glean from a pamphlet of thirty pages the statistical essence of thousands of pages.

It is with no desire to interfere with the work of any other department that this condensation is undertaken. Its sole purpose is to make statistics popular by making them easily attainable,—to express great facts in short sentences,—so that the active, pushing American can read as he runs, and remember what he reads.

But more should be done. To borrow an old phrase which has done service many times on the threshold of progress,—“Statistics is in its infancy.” Permanent provisions should be made for the annual publication of the statistical abstract of the United States now issued by the Bureau of Statistics of the Treasury Department. Chief Brock has submitted to Congress the draft of a bill which provides that the various departments of the Government shall supply the statistics required for the abstract. But even if this abstract is provided for, but half is done that is required. The material must be still further condensed and sent broad-cast over the country in the form of short abstracts in text form, and in the form of items so arranged as to be available for copy by simply cutting from the sheet, which should be printed on one side only.

But still more should be done. There should be a Central Statistical Bureau of the United States to collect and assimilate the work of American and foreign statistical offices and bring their work into shape for comparison. As such an office would not undertake original investigations, but would deal with official reports, or with material collected by other parties, it would not be necessary that such an office should be conducted by the Government. It would be much

better to have it organized on a private commercial basis. Then those who pay can choose their statistical diet. Republicans can call for and obtain figures to show the benefit of protection, while Democrats can ask for and secure those statistics which indicate the prospective advantages to be derived from an approximation to free trade. Even the Prohibitionists could purchase figurative crumbs of comfort.

Such an office would supply its authorities with all its tabulations and presentations. It would be an office free from partisanship, for its proprietors would conduct it on a professional and financial basis. As long as it maintained this independent position its statistical value would be acknowledged. If it allied itself with a political party, it would soon be known by its fruits, and from the position of the judge it would fall to that of the advocate. A dry goods dealer does not keep one class of goods for Republicans and another for Democrats, —and if he decided to sell only to the members of one party, he would violate the prime principle of trade,—sell all that you can and make as much as you can.

Such a bureau, from its vast collection of official and personal statistics, could prepare abstracts and items for the use of newspapers. It could supply special statistics for editors, writers, merchants, statesmen, and others. It could publish small pamphlets on live subjects, giving in condensed form, at a small price, the results of original investigations from the published reports of statistical offices in all parts of the world. Its translators would put into graphic English, within a few days after their receipt in this country, the reports of foreign statistical offices, and the latest productions of individual foreign statisticians. Such a bureau would naturally publish a statistical paper,—probably a weekly. It could contain original articles, biographies of leading statisticians, with portraits, accounts of the principal statistical offices in the world, personal items, reviews of statistical works, a record of the progress made in practical statistics, —in fact, be “a trade paper,” and a means of communication for those connected with or interested in the science. Such a statistical office, conducted in a business manner, would have to be just to all its patrons. The study of statistics, and particularly their preparation, frees a man from partisanship,—for partisanship often antagonizes justice,—and the statistician who seeks truth cannot, in justice, tamper with figures or conceal facts. Every mooted question, when the

facts are obtained, shows that the parties on both sides had reasons for their opinions, and the agitator who, craving notoriety or risking popularity, cries out that a giant wrong exists, has done the public a service even if the facts show that his giant was only a puny dwarf. Negative statistics are often more convincing than positive ones.

To the American Association, to the Annual Convention of Chiefs and Commissioners of Labor Bureaus and kindred associations, the people of America must look for the organization, or, at least, generous encouragement, of all legitimate plans for making statistics popular,—that is, having statistical truths form part of the education of the progressive American. We do not expect that an individual will enter a drug store and help himself to medicine. The medicine must be dispensed. The liquids may be given in drops or teaspoonfuls, the solids in powders or pills. So the mass of statistics must be cut up and dispensed in small doses.

The newspaper editor, the statistician, the special agent for abstracts and items, the statistical weekly, monthly or quarterly, the central statistical bureau,—in fact, all dispensers of statistics, must supply them in such form that they will catch the eye, appeal to the mind and linger in the memory. This, in my opinion, is the true answer to the inquiry, "How can statistics be made popular?"

Another way in which statistics can be made popular is for our statistical associations to have annual dinners or banquets. Speeches upon the intimate and vital connection of statistics with the questions of the day and progressive legislation would be in order. Editors, authors, and statesmen would be appropriate guests at such banquets, and the reports of the occasions in the newspapers would attract the attention of the public and tend, in no small degree, to add to the growing popularity of statistics.

MEETING 408.

*The Purification of Water by Metallic Iron.*BY MR. EASTON DEVONSHIRE.

The 408th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, December 11th, at 8 P.M., Prof. T. M. Drown in the chair.

The records of the previous meeting were read and approved. The chairman then introduced Mr. Easton Devonshire, of London, England, who read a paper on "The Purification of Water by Metallic Iron."

MR. DEVONSHIRE said: I think that were any special proof needed to show how rapidly this country is arriving at the age of maturity it might be found in the increased attention which is given not only by scientific men and professional sanitarians, but by the people at large, to questions affecting public health. Of these questions not the least important is that of the quality of the water we are to drink, and the precautions that should be taken to prevent this necessary of life from being a possible source of danger to the health of the consumer. In the phenomenally rapid growth of cities in this great country sufficient attention has not been paid, in the first instance, to sanitary considerations, which have almost necessarily been postponed for want of time to give them the prominence they deserve. Again, the increase of population and the growth of industries of all kinds in the neighborhood of the waterways, which were the cause of their location, have altered the conditions which originally permitted, if they did not justify, the utilization of natural waters for the drinking supply of cities and towns. In the older countries of Europe, long since densely populated, it has for years past been found necessary to endeavor to counteract by artificial means the inevitable pollution of sources of water supply at one time deemed harmless. Also, the advancement of science has proved the dangers to public health which impure water offers and which were, until comparatively recent times, but imperfectly recognized.

The oldest method of artificially improving impure water is that of filtration through sand. It is the general practice in England and in many parts of the continent of Europe to submit water drawn from rivers, or other sources not entirely free from suspicion of contamination, to the process of sand filtration.

This process consists of allowing the water to percolate through a layer of sand two or more feet in thickness at a speed sufficiently slow to remove at least a considerable portion of the suspended impurities. The action of the sand filters, worked as they are in ordinary practice, is purely mechanical, the dissolved organic matter not being reduced in any important proportion. They are, however, capable, as has been shown by Piefke, of arresting bacteria to an extent which their porosity would not seem to render possible, the explanation being found in the formation, after several days' working, of a sticky film or membrane which Piefke terms "bacteria jelly," to which the micro-organisms adhere when the speed at which the water passes through the sand bed is maintained at a slow and unvarying rate. This speed will differ according to the nature of the water and the standard of improvement aimed at. Under favorable conditions it should not exceed sixty gallons per square foot per day, while half this speed will fail to remove the color due to finely divided clay or peat so frequently met with in river and impounded surface waters.

In 1879, when a charter for the water supply of the city of Antwerp, in Belgium, was granted by the municipal authority to an English firm, permission was given to use the river Nethe as the source of supply, on condition that its water should be submitted to a careful filtration through sand before distribution.

Before commencing to construct the works, however, the proprietors foresaw that simple sand filtration would fail to remove the peaty color from the water and render it sufficiently attractive to the eye to compete with the old established supply obtained from the shallow wells with which each household was provided. It was recognized that whatever superiority the sand-filtered river water might be shown to possess over the contaminated well water, the commercial success of the undertaking would be endangered by the inferior appearance of the new supply. Several chemically acting filtering materials were known to be capable of removing the objectionable color, and, after an examination of the merits of each of them, the material known as

Bischof's spongy iron was selected. Successful experiments were made and filters containing spongy iron were designed and constructed.

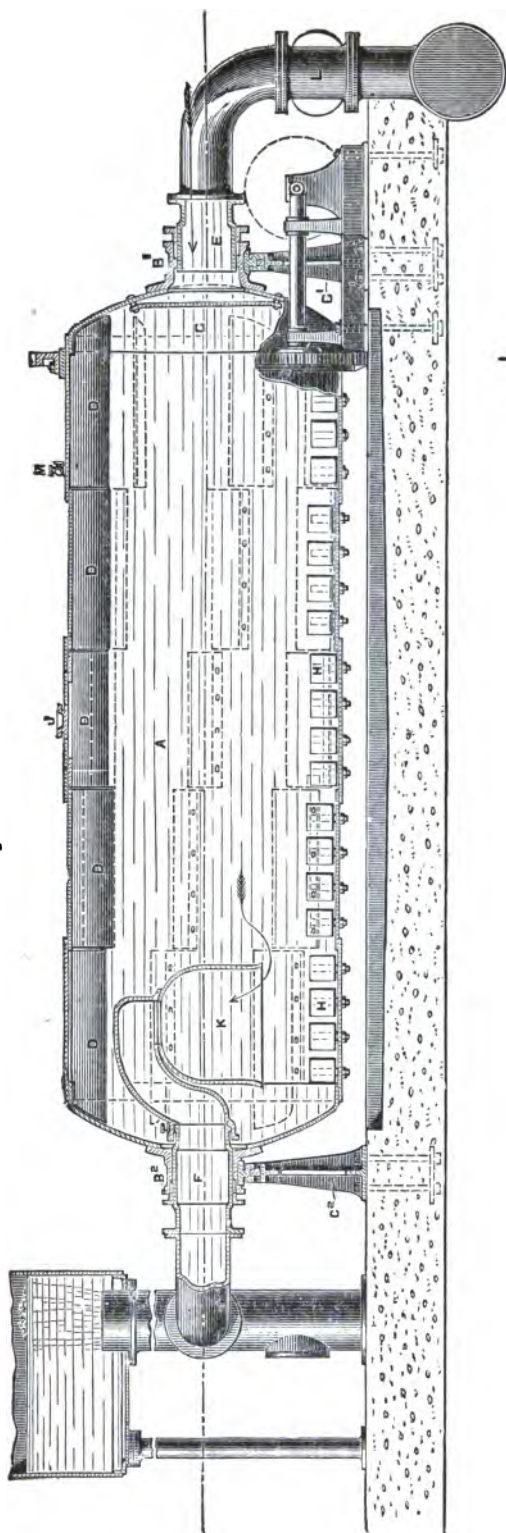
Spongy iron is obtained by roasting hematite ore to a point just short of fusion, the metal being rendered porous or spongy by this operation. Some 900 tons of this form of iron, mixed with three times its bulk of fine gravel, were used to form three filter beds. The river water percolating through these beds took up a portion of the metal, forming a ferrous salt, which by subsequent contact with the air was precipitated as ferric oxide, and, acting as a coagulant, allowed the water to be strained through a bed of sand, and to issue bright and colorless.

The desired improvement in appearance was thus obtained, and at the same time the water was found to be purified to a remarkable degree. The Bischof process, though costly, thus promised to solve the problem how to utilize an impure natural water without danger to public health.

For nearly three years the Bischof filters realized expectations, but gradually, as the demands of the city increased, it was noticed that the daily delivery of the filters was decreasing in quantity. Investigation showed that the material was caking and rusting together, and was being clogged with the substance formed by its chemical action on the dissolved organic matter of the river water. Finally, when great expense had been incurred in efforts to maintain the porosity of the filters, William Anderson, the consulting engineer of the works, designed a method of overcoming the mechanical difficulties of filtration. This method, known as the Revolving Purifier system of purification, is the invention which my paper is to treat of tonight.

The somewhat long introduction I have given it is for the purpose of showing what was the necessity for the invention and what were the difficulties in water purification and filtration it had to overcome.

In Bischof's, as in all other systems of chemically-acting filters, the water is brought into contact with the purifying medium by percolating through it. Anderson reversed the principle by designing an apparatus in which the purifying medium is continuously showered down through a flowing stream of water. The apparatus by which the result is effected consists of a cylinder A (see Fig.), supported in a horizontal position by hollow trunnions B_1 B_2 revolving in pedestal bear-



ings C_1 , C_2 , placed one at each of its extremities. Within the cylinder are a series of short curved shelves $D D D$ arranged in steps at equal distances round its circumference, and reaching from end to end. In the place of a sixth row of curved shelves is a line of small square plates $H H H$, which, by means of nuts outside the cylinder, can be set at an angle with the axis of the purifier. These plates serve to direct the shower of iron back towards the inlet end of the apparatus, and so to counteract the tendency of the current of water to carry the purifying material forward. Through the hollow trunnions, which are provided with stuffing boxes, pass the ends of inlet and outlet pipes E and F , which bring and which carry off the water to be purified. Facing the inlet pipe E is a circular distributing plate G , secured at a distance of $\frac{5}{8}$ inch or $\frac{3}{4}$ inch from the end of the cylinder, serving to distribute the water radially on its entering the cylinder, and prevent its flowing in a direct current along the axis of the apparatus. The inner end of the outlet pipe is fitted with an inverted bell-mouth K , carried down as near to the bottom of the cylinder as the shelves will allow, and intended to prevent the finer particles of iron from being carried out by the current of water. A rotary motion is given to the cylinder through gearing working into an annular spur-wheel I , surrounding one end of the cylinder.

Through a suitable hand or man-hole J iron in a moderately fine state of division is introduced into the cylinder and spread evenly along the bottom in sufficient quantity to occupy one-tenth of the capacity of the cylinder.

When the Revolving Purifier is to be set in motion, the sluice-cock L , provided at the inlet, is opened and the cylinder filled with water, the air being expelled through the air-cock M , which at that time must be at the top of the cylinder. When all the air is expelled the air-cock is shut, and the apparatus is set in motion by a small steam-engine or other suitable form of motor, the speed of rotation being about six feet per minute at the periphery. By this rotary movement the shelves are successively caused to scoop up the iron granules, which at starting are spread evenly along the bottom of the cylinder, and to shower them down through the water. By means of the sluice-cock L , the flow of water may be regulated to the speed required to give the duration of contact with the iron found necessary for efficient purification under the particular circumstances.

In his first experiments Anderson used spongy iron, which was up to that time supposed to possess special merit as an active purifier. Experiment, however, showed that scrap iron, in any convenient form, was equally active. The great difference in cost of the two materials of course made this discovery a valuable one.

The objections to the practical working of spongy-iron filters on a large scale were two-fold. First, the rusting together of the mass; and, secondly, the coating of the material by the products of its own chemical activity, whereby the contact between the metal and the water was continually being impaired.

The revolving purifier obviates both of these objections in the first instance by showering a small quantity of the material loosely through the water, and in the second by the automatic cleaning which each particle of the metal gets by rubbing against its neighbors.

The theory of the process is the formation in the water passing through the purifier of a protosalt of iron, through the solution of a minute portion of the metal by the carbonic acid and oxygen contained in the water. On issuing from the cylinder into the open air the protosalt is converted by further oxidation into the insoluble form of ferric oxide. In its formation the ferric oxide entangles the suspended matter, and oxidizes the organic ingredients of the water. The distributive action of the ferric oxide in the organic matter has been described as being similar to that of rust stains or iron mold on linen, the fibers of which are apparently burnt up.

Micro-organisms are at the same time caught and held in the precipitate. Dr. Edward Frankland goes farther and considers that they are actually destroyed, the iron having a toxical effect. Whatever may be the true facts of the case, it has been proved by repeated analysis that the purification of the water is effected by the time the precipitate is completely formed. Subsequent sand filtration has only to remove the precipitate by mechanical straining.

Prof. Kemna of Antwerp, who has studied this process very fully, has expressed the opinion that the micro-organisms are to a great extent arrested by the film of oxide formed on the surface of the sand bed. I, at one time, expressed the same view, but recent experiments lead me to think that, as far as the bacteria originally present in the water are concerned, the precipitate alone is capable of holding them. Of course in practical working the purified water receives continually

a fresh supply of bacteria from the air. These are certainly removed during filtration, and here the coating of oxide, which the sand receives, is of great value, replacing the gelatinous film and the membrane formed by the growth of algæ on ordinary sand filters, as explained by Piefke in his experiments with the Berlin filters. It is also possible that the ferric oxide film on the sand removes the last trace of free ammonia, the entire absence of which is characteristic of the iron process.

Weekly analyses of the Antwerp water before and after filtration show that in actual practice on a large scale the albumenoid ammonia is reduced to one-third of its original amount,—free ammonia and nitrous acid entirely disappear and nitrates are brought down to the smallest trace.

As regards micro-organisms, continued examinations by Koch's gelatine test show that from the number of 50,000 to 100,000 in the river water at Antwerp, the highest figure during the whole of last year in the filtered water, was twenty colonies per cubic centimetre, the average being only four or five colonies. This means practically the sterilization of the water. The figures are the more remarkable as they are the results obtained daily under all conditions of the water and in the fifth year of the uninterrupted working of the process.

The principle followed out in this process differs essentially, in one important respect, from that of the high pressure system of filtration which, in conjunction with the use of alum as a coagulant, has been the subject of many patents in this country.

With high pressure filters the coagulated impurities are strained out of the water while the latter is forced, at a high rate of speed, through a compressed bed of sand of comparatively small area. The effect of the high rate of speed is to impregnate the whole depth of the filtering materials with the coagulated impurities. At a given moment the filter is clogged up through its whole depth, and must be washed throughout by a reverse current before being used again. In Anderson's process care is taken so to regulate the speed of filtration that the sand bed shall be capable of retaining *at its surface* the precipitate formed by the iron. In this way, as long as the filter maintains a specified delivery under a constant and low pressure, the certainty exists that the mass of the sand is absolutely unfouled, and water is obtained of the same degree of purity from first to last.

Further, as a matter of economy, slow-running filters have proved the best. Although of much greater area, the fact that they require cleaning only once in six weeks or two months, as against the daily washing given the high pressure filters, makes their working cost the lower of the two.

When the difference of cost of scrap iron and alum is taken into account, comparative statements of the working cost of the two processes show that for similar waters the iron process does not cost more than half the alum process.

From what may be called the sentimental point of view, the avoidance of the use of chemicals, whether alum or salts of iron, such as perchloride or sulphate of iron, is a strong argument in favor of the Anderson process for the treatment of potable waters.

The actual working cost of the revolving purifier process varies with the nature of the water treated, and may be considered as being more or less in proportion to the activity of the particular water in contact with the metal and the readiness with which the precipitate forms. A clear water, free from mud and suspended impurities, is by no means necessarily the cheapest purified, but with waters like the Mississippi, containing an immense quantity of finely suspended clay as well as much easily separated mud, a few minutes agitating with plate punchings produces such a coarse and voluminous precipitate that 90 per cent of it can be arrested by obstacles placed in the channel along which it runs on its way to the filter bed. On the other hand, water containing a large quantity of organic matter of certain kinds will retard the precipitation of the iron, and keep the precipitate in a finely divided condition until the sand is reached. It is the finely divided matter, be it a precipitate of ferric oxide or suspended clay, which shortens the life of a filter. Thus, to go to an extreme case, clean sand carried mechanically in water can be strained out with the greatest facility without choking the filter, retaining it for a very long time. With the iron process, where a voluminous coarse precipitate is formed, the whole bulk of it may be sent on to a sand filter, and yet the life of the filter will be three or four times as long as with a fine precipitate of small volume.

The working of the process at Antwerp and at Dordrecht, in Holland, serve as excellent comparative illustrations of this. At Antwerp the water is charged with much organic matter, both vege-

table and animal, but contains comparatively little finely suspended mud.

Before the introduction of settling reservoirs, the filters had to be scraped on the average once a fortnight. At Dordrecht, where the water is organically much purer, but holds a great deal of fine clay in suspension, the filters run for five weeks, although the water goes direct onto them from the purifier.

I stated before the Franklin Institute some eight months ago that for quantities of five million gallons per day and upwards the working cost of the process in no case would exceed two dollars per million. I have since received the figures of cost for the year 1889. Although on the average less than 750,000 gallons were pumped daily, this being under half the capacity of the plant, the 234 million gallons pumped in the year cost only \$257, a fraction over one dollar per million. Of course with large volumes the cost per million decreases.

The paper was illustrated by views shown on the screen and by experiment. A short discussion followed, after which the meeting was adjourned with a vote of thanks to the speaker for his very interesting lecture.

MEETING 409.

A New Method of Study in Telephony.

BY PROF. CHARLES R. CROSS.

The 409th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, January 8, 1891, at 8 P.M., Mr. N. M. Lowe in the chair.

After the reading of the records of the previous meeting and the election of new members, the chairman introduced Prof. Charles R. Cross, of the Institute, who read a paper on "A New Method of Study in Telephony."

Prof. CROSS said: The character and extent of the motions of the electrodes of a microphone transmitter, when actuated by sound-waves of different degrees of intensity, is a subject in telephony of by

no means slight importance, but to which very little study has been given. The present paper describes the results of some observations relating to this subject, which have been made at various times during the past two years.

Several years ago an attempt was made by Mr. W. W. Jacques and the writer to gain some knowledge as to the amplitude of the vibrations of the hammer electrode of a microphone, by observing it with a microscope while in operation, and noting the extent of the blurred portion of the image. The results, though giving all that could be expected from so crude a method, were not very satisfactory so far as definite measurement was concerned.

It afterwards occurred to the writer that the matter might be studied more completely by the use of the stroboscopic method, and an arrangement of apparatus was adopted by which the motions of the electrodes could readily be observed.

This was done in the following manner. The microphone to be studied was placed in the field of a microscope, whose line of collimation was horizontal. Behind the microphone, at a suitable distance, was placed a Helmholtz mercury interrupter, with a tuning-fork making 128 vibrations per second. The extra current due to the electromagnets of the interrupter was quite large, so that a brilliant spark was obtained at each rupture of the circuit, as the platinum style of the interrupter left the mercury. The interrupter being properly placed, and the light of the spark concentrated by a lens, quite a bright field was obtained, against which the electrodes were seen projected as silhouettes. The light, though intermittent, of course seemed continuous, since the sparks were so numerous. When good definition was obtained, the microphone was set in operation, usually by means of an organ-pipe placed at a convenient and variable distance, and in some experiments by the voice. The pipe was blown by a constant blast, and great uniformity of intensity in the sound was secured. An open C_3 organ-pipe making approximately 256 double vibrations per second was commonly used, its pitch being variable to a moderate extent by shading the mouth or the opening at the top.

So long as the pipe was an exact octave in pitch above the interrupting fork, the electrodes of the microphone as seen with the microscope appeared to be at rest; but if the interval was slightly disturbed, the stroboscopic effect was observed, and the electrodes seemed to

move slowly through their complete course. The rate of this apparent vibration was of course dependent upon the deviation of the pipe from exactness in its interval with the fork, and could be varied at will within quite wide limits.

The extent of the motion of the electrodes could be determined by observing the grains of dust which adhered to them, or some definitely marked roughness on their surface. Measurements were made by means of a spider-line micrometer, the wires of which were placed at a convenient distance apart, and the amplitude of the motions of the selected points of reference on the microphone was determined by estimating the relation of their apparent motion to the distance separating the wires of the micrometer. This last distance was frequently varied to diminish the liability to error from a possible bias of the observer towards an agreement with earlier results.

In the experiments described in the present paper, the electrodes were generally so adjusted that the motion of the anvil electrode was too small to be observed. Under these circumstances the observed motion of the hammer electrode, as measured by the micrometer, was the motion of this relatively to the anvil electrode, which is of course the quantity to be determined rather than the actual excursion of the hammer electrode.

The microphone was placed in circuit with a battery and the primary of an induction coil, whose secondary contained a receiving telephone. With this arrangement the effect on the ear of the electrical variations due to the various values of the excursions of the electrodes could readily be observed. In many cases a second observer was stationed at the receiving telephone, which was then placed in a separate room.

Magnifying powers were used of from 50 to 1000 diameters. With the higher powers the use of an objective of short focal length was difficult on account of the small working distance, so that, although even as short a focus as $\frac{1}{16}$ in. was sometimes employed, it was found much preferable to obtain the needed magnification by the use of short focus eye-pieces.

The brilliancy of the electric spark was amply sufficient for illumination of the field, even with the highest magnification employed; a fact which calls attention vividly to the enormous "instantaneous intensity" (so to call it) of that light. Considering the excessively

brief duration of the spark and the very small quantity of matter illuminated, it seems unquestionable that the intrinsic brilliancy is far greater than that of the electric arc, a view fully supported by the results of spectroscopic study.

Various forms of microphone were observed, but the general features characterizing the actions studied were common to them all. As the intensity of the sound acting on the microphone was increased by approaching the organ-pipe to the diaphragm, the motion of the hammer electrode, at first absolutely invisible, was seen gradually to increase until, when the intensity was very great, the motion was excessive, the anvil electrode being violently pushed aside, and the hammer leaving it on its return motion, so that the circuit was broken at every vibration. At the same time bright sparks were seen between the electrodes. To the ear the simultaneous acoustic changes in the sound transmitted were very striking. The sound of the pipe was distinctly audible, and its quality clear, with motions of the hammer electrode far too slight to be observable. As the sound actuating the telephone became louder, and the excursion of the electrode became visible, the quality continued good, the sound transmitted growing louder; and then, as the excursion increased further, the quality gradually changed, shrill false notes made their appearance, and the sound began to grow harsher, until finally, when breaks appeared in the current, the sound was excessively harsh, and entirely devoid of musical quality. Long before this, however, the characteristic quality of the organ-pipe disappeared.

The following tables will illustrate the results obtained. In making many of the measurements I worked in company with Mr. W. W. Jacques, whose observations were always in substantial accord with my own. A large number of observations have also been made, under my direction, by Messrs. A. W. Jones and F. L. Dame, students in the laboratory, whose work has been performed with conscientiousness and accuracy.

The microphone used in most of the experiments was one in which the anvil electrode was a "pendulum electrode," suspended by a vertical rod, hinged at the top, and is weighted so as to give to it a proper mass. The desired normal pressure could be obtained by sliding the point of suspension laterally so as slightly to incline the supporting rod, and further, by adding a weight so as to exert a proper

leverage, if this was desired. The hammer electrode was pointed and carried by the diaphragm, which was of mica. The sounding pipe was gradually removed from or approached toward the microphone. Care was in all cases taken to keep the wind pressure constant. A single Leclanché cell was ordinarily used, though in a few cases a Grénet cell was employed.

In the various tables, the excursions of the electrodes are in all cases given in fractions of an inch. In designating the material of the electrodes, that of the anvil is stated first.

Tables I to III show the results obtained when both electrodes were of carbon; Tables IV and V, when the anvil electrode was of carbon, the hammer of platinum. Tables VI to VIII contain results of observations made with a modified form of transmitter, in which the anvil electrode was also somewhat heavier than in the earlier experiments.

TABLE I.

ELECTRODES, CARBON, CARBON.—*Magnification, 50 diameters.*

Excursion.	Character of Sound.
1000×10^{-6} to 700×10^{-6}	Constant breaking and sparks. Electrodes visibly separating.
600×10^{-6}	Constant sparking. Electrodes occasionally seen to separate.
200×10^{-6}	Occasional breaks and sparks.
200×10^{-6}	Scratchy sound, no sparks.
No visible motion.	Sound clear and smooth.

TABLE II.

ELECTRODES, CARBON, CARBON.—*Magnification, 50 diameters.*

Excursion.	Character of Sound.
1000×10^{-6} to 600×10^{-6}	Constant sparks; electrodes separating.
300×10^{-6} to 200×10^{-6}	Harsh; occasional breaks and sparks.
150×10^{-6}	Scratchy.
No visible motion.	Clear and smooth.

Whenever the excursion of the hammer was greater than 100×10^{-6} the sound was very scratchy and harsh.

TABLE III.

ELECTRODES, CARBON, CARBON.—*Magnification, 160 diameters.*

Excursion.	Character of Sound.
350×10^{-6} to 300×10^{-6}	Loud, noisy, harsh.
250×10^{-6} to 200×10^{-6}	Very scratchy.
120×10^{-6} to 80×10^{-6}	Scratchy, but less than before.
150×10^{-6} to 100×10^{-6}	Scratchy, but with high overtones.

At the lowest amplitude given in Table III the quality of the sound of the pipe was first heard, but a still less amplitude was necessary for its satisfactory reproduction.

TABLE IV.

ELECTRODES, CARBON, PLATINUM.—*Magnification, 160 diameters.*

Excursion.	Character of Sound.
250×10^{-6}	Constant sparks and breaks.
120×10^{-6}	Scratchy; occasional sparks and breaks.
70×10^{-6}	Raspy.
50×10^{-6}	Quality distinct, but high squealing overtones present.
20×10^{-6}	Quality better; fewer high overtones.
Less than 20×10^{-6}	Quality better; some high overtones still audible.

The pipe had to be carried twice as far away from the transmitter as in last measurement, to a distance of eighteen inches, before the quality became really excellent.

TABLE V.

ELECTRODES, CARBON, PLATINUM.—*Magnification, 150 diameters.*

Excursion.	Character of Sound.
120×10^{-6}	Very scratchy; occasional sparks.
60×10^{-6}	Squealing, high overtones.
40×10^{-6}	Fair quality; high overtones prominent.
$< 20 \times 10^{-6}$	Good quality; a little rough.
400×10^{-6}	Constant breaking.
60×10^{-6}	Very raspy.
40×10^{-6}	High overtones strong.
20×10^{-6}	Quality good.

TABLE VI.

ELECTRODES, CARBON, PLATINUM.—*Magnification, 700 diameters.*

Excursion.	Character of Sound.
200×10^{-6}	Rough, but pitch discernible.
80×10^{-6}	Rough, pitch distinct.
30×10^{-6}	Smooth, with high overtones.
30×10^{-6}	“ “ “
20×10^{-6}	Quality good; some high overtones.
10×10^{-6}	Good quality.
25×10^{-6}	Smooth, with high overtones.
30×10^{-6} to 40×10^{-6}	High overtones prominent.
80×10^{-6}	Harsh and rough.

TABLE VII.

ELECTRODES, CARBON, PLATINUM.—*Magnification, 940 diameters.*

Excursion.	Character of Sound.
1000×10^{-6} to 800×10^{-6}	Scratchy, with breaks.
100×10^{-6}	Rough; with high overtones.
80×10^{-6}	Wheezy, with high overtones.
40×10^{-6}	Smooth, but with high overtones.
30×10^{-6}	“ “ “ “
60×10^{-6}	Rough, with high overtones.
50×10^{-6}	Harsh, with high overtones.
40×10^{-6}	Smoother.
30×10^{-6}	Smoother, with high overtones.
20×10^{-6} to 30×10^{-6}	Good quality, high overtones present.
20×10^{-6}	Good quality.

TABLE VIII.

ELECTRODES, CARBON, PLATINUM.—*Magnification, 940 diameters.*

Excursion.	Character of Sound.
1000×10^{-6}	Harsh and screamy.
2000×10^{-6}	“ “ “
1000×10^{-6}	High overtones heard; no distinct pitch transmitted.
400×10^{-6}	High strident overtones present.
100×10^{-6}	High overtones still present.
60×10^{-6}	Sound wheezy.
30×10^{-6}	Sound smooth.
20×10^{-6} to 10×10^{-6}	Quality good.

The differences in the effects obtained with a microphone in which both electrodes are of carbon, as compared with one in which one of the electrodes is of platinum, are well known to everyone who has considered the subject. While with the latter it is more easy to produce an actual break of contact between the electrodes than with the former when the sound is increased, on the other hand the quality is much more satisfactorily reproduced, and does not so rapidly disappear on increasing the loudness. These differences were clearly noticed in the observations. Thus, for slight excursions of the hammer electrode, the quality of the sound with two carbon electrodes was found to be less satisfactory than when the hammer was of platinum, although in the latter case the point of actual breaking of circuit and sparking was usually reached with a less excursion than in the former one. Evidence of these differences appears in the tables just given.

It must be observed that, while the figures given in the tables show what is the maximum amplitude of vibration of the electrodes consistent with the transmission of quality, they entirely fail to indicate the excessive minuteness of the least excursions which are capable of this result. How minute these sometimes are may be inferred from the following observation.

With a microphone having a somewhat heavy anvil electrode, the organ-pipe was gradually moved away from the diaphragm, and the diminishing range of motion of the electrodes noted in the usual manner. When the pipe was at a distance of three inches the motion of the electrodes was too slight to be visible, although this could have been seen readily with the low magnifying power employed if it had been as great as $\frac{1}{1000}$ in. The pipe, still blown with the same loudness, was then carried farther and farther away. At a distance of thirty-six feet, which was the most distant point from the microphone in the room, the sound of the pipe was still distinctly though faintly audible at the receiver placed in circuit with the microphone, and in a distant apartment.

The results shown in the preceding tables give an idea of the phenomena observable with a microphone of the structure employed. Inasmuch as the primary object of the measurements was to obtain some idea of the actual value of the excursion of the electrode, the mass and normal pressure of the electrodes were not particularly con-

sidered, except that they were so adjusted as to give good transmission with moderate loudness of the sound actuating the microphone. But it would of course be expected that the numerical value of the relative excursion of the electrodes corresponding to any given character of sound would vary with the mass of the anvil electrode and with the normal pressure between the electrodes. Two separate sets of observations were made to observe the effects of such variations by Messrs. Jones and Dame.

In all experiments of the nature of those under consideration, it is very difficult to get any fixed standard of quality to which to refer such results as the present. Different observers differ to a certain extent in their estimate of the excellence of the quality reproduced. But the point at which the distinctive quality of the transmitted sound disappears is quite well marked, and a very slightly increased vibration of the hammer electrode causes great harshness to result. For this reason the name "critical point," originally suggested by Mr. Jones, has been given to this limit, and the excursion corresponding to it has been particularly noted in tests of the varying effects of mass and pressure.

The transmitter used had its anvil electrode suspended like a pendulum, as before. In order to vary the mass without varying the normal pressure a horizontal wire was suspended beneath the anvil electrode and rigidly attached to it. The middle point of the wire was vertically beneath the point of suspension of the electrode. The masses added consisted of small copper washers weighing 11 grams each. By adding two of these whenever the mass was to be increased, and placing one on each side of the middle point of the horizontal wire, the mass of the electrode was increased, while the normal pressure remained substantially constant.

The results of these experiments show that the value of the excursion of the hammer electrode corresponding to the "critical point," and presumably, therefore, the excursion corresponding to any given degree of excellence in the reproduction of quality, at first rises very rapidly as the mass of the anvil electrode is increased, but soon reaches a maximum value, which is not altered by further increase of mass. The rise appears to be less rapid when both electrodes are of carbon than when one or both of them are of platinum. Also, when both electrodes are of carbon or both of platinum, the maximum and

permanent excursion at the critical point is considerably less than when the hammer electrode is of platinum and the anvil of carbon,—a fact which goes to explain the well known excellence of a microphone employing these last materials. Further experiment is desirable, however, before fully accepting this explanation. Furthermore, variations in the surface and shape of the electrodes are likely to modify these values to a certain extent.

A further series of measurements was made in order to ascertain what effect was produced by a variation in the normal pressure between the electrodes.

In order to do this, a wire was caused to project backward from the anvil electrode, and small weights were hung upon the end of it. The pendulum electrode with this projecting wire constituted a bent lever whose arms were easily measured, thus enabling the normal pressure due to a given weight to be calculated.

It appears from these experiments that the value of the excursion corresponding to the critical point rises with increase of normal pressure, soon attaining a maximum and constant value. The pressure at which this maximum value was reached was greatest when both electrodes were of platinum, and least when the hammer electrode was of platinum and the anvil of carbon. When both electrodes were of carbon the value lay between these two extremes. The unexpected result was also reached that the value of the maximum excursion was much greater when both electrodes were of platinum than when both were of carbon. It was least when the hammer was of platinum and the anvil of carbon.

A series of observations was also made upon the microphone of the Blake transmitter. These presented considerable difficulty on account of the construction of the parts of that instrument, and only a low magnification could be used. Three sets of measurements were taken, the first with a very light normal pressure, the second with the ordinary pressure, and the third with a very heavy pressure. With this microphone in its proper condition both electrodes moved. It was therefore necessary to subtract the excursion of the anvil electrode from that of the hammer, in order to obtain their relative motion. The results reached are given in Table IX. The total excursion of the hammer electrode, and its motion relative to the anvil, are given as nearly as they could be measured.

TABLE IX.

BLAKE TRANSMITTER.—ELECTRODES, CARBON, PLATINUM.

a. *Light Normal Pressure.*

Total Excursion.	Relative Excursion.	Character of Sound.
	$< 25 \times 10^{-6}$	Good quality, very faint.
50×10^{-6}	25×10^{-6}	" " clear.
100×10^{-6}	50×10^{-6}	Overtones strong.

b. *Medium Normal Pressure.*

	$< 25 \times 10^{-6}$	Good quality, very faint.
75×10^{-6}	25×10^{-6}	" " clear.
100×10^{-6}	50×10^{-6}	Overtones strong.

c. *Heavy Normal Pressure.*

	$< 25 \times 10^{-6}$	Good quality, very faint.
100×10^{-6}	25×10^{-6}	" " clear.
150×10^{-6}	50×10^{-6}	Overtones strong.

These results, although of only approximate exactness, are interesting, as they show one cause of the excellence of the Blake transmitter in practice, in that the mode of support of the electrodes allows of very considerable variations in the absolute motions of both of them without material change in their relative motions.

MEETING 410.

A Course of Instruction in Highway Engineering.

BY PROF. C. F. ALLEN.

The 410th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, January 22nd, at 8 P. M., Prof. G. F. Swain in the chair.

After the reading of the records of the previous meeting and the election of members, the chairman introduced Prof. C. F. Allen, of the Institute, who read a paper on "A Course of Instruction in Highway Engineering."

Prof. ALLEN said : What is the value and wherein lies the advantage of a good road ? One answer to this query may be found in the fact that about one hundred years ago it cost \$5 to haul a barrel of flour 150 miles over the imperfect roads characteristic of that time ; today on the railroad, the perfection of roads, a barrel of flour can be carried from Chicago to New York, a distance of 1000 miles, for the small sum of 50 cents, or one-tenth the money, although the distance is more than six times as great. In other words, Chicago is for commercial purposes nearer to New York than was Stamford one hundred years ago, and the farming lands of Minnesota, then quite valueless because inaccessible, are today of greater importance and value than most of the farming lands of New England. Between two roads of the ordinary kind, one good and the other bad, a difference of a similar character exists but in smaller degree. If the road is improved so that a horse can draw two barrels of flour where before he hauled one, then for any given amount of traffic it costs no more to ship goods a distance of 20 miles than it had formerly cost for 10 miles. The effect of good roads is not felt commercially alone ; but socially and politically they are at least of equal importance. In the opinion of so eminent a writer as John Stuart Mill it was largely to her roads that Rome through many centuries was indebted for the dominion of the world, and neglect of the means of sure and swift communication was no unimportant part of the reason why Greece failed of universal empire. In modern times, again, Spain furnishes an example of bad roads and of waning powers, while Switzerland, in spite of mountainous and sterile lands, is prosperous in consequence of good roads for internal communication. Roads are, in fact, essential to provide the very necessities of life. Native tribes in uncivilized lands are constantly exposed to the dangers of starvation, while in civilized regions famine is practically unknown,—a change of conditions due largely or wholly to improved means of communication.

It then becomes pertinent to ask : What is the condition of the roads of the United States ? Close about us in the prosperous cities and towns of New England such attention is paid to the subject that roads of a disgraceful character are not common, although the opportunity for improvement is great. "In the Western wheat region," it is stated in the Tenth Census of the United States, "according to the estimates received, it costs the ordinary farmer more to carry a bushel

of wheat a mile than it does the ordinary railroad to carry a ton ; and, consequently, when we get west of Lake Michigan it rarely pays to grow wheat more than twenty miles from rail or water transportation." On a good "Macadam" surface there can be hauled about four times the load possible on an ordinary dirt road. Owing to the increased labor of hauling on poor roads, it is estimated by Prof. Jenks, in his "Road Legislation for the American State," in a computation based on the number of horses in the state, "that the cost of poor roads to such a state as Illinois is more than \$15,000,000 per year."

We gather in such ways some idea of the importance of good roads. It is not enough, however, in order to justify the establishment of a distinct course of instruction in Highway Engineering, that we are able to recognize the importance of good roads. A school of engineering should, it is true, be proud to lead engineering opinion and practice, but it is not called upon to lead unless some one stands ready to follow. It is requisite that public attention should be sufficiently aroused to recognize that good roads are of the greatest importance, and that instruction in Highway Engineering, as a special feature, is a definite need. Of the fact that increased public attention is being given to this subject, there is abundant evidence. While little in the way of permanent results has so far been reached, yet there have been vigorous efforts towards improved highway legislation in several of the states of the Union,—New York, Pennsylvania, and Massachusetts being among the number. Looking at the matter from a different standpoint, it is found that within the past year two sets of competitive essays upon roads and road building have been prepared, with prizes aggregating \$1000 or more. Within the past year, also, there has been held, for the first time, a street-paving exhibition (in Indianapolis), and there has been established a monthly periodical, "Paving," devoted mainly to highway questions. The time, then, is ripe for devoting special attention to highway engineering as a branch of civil engineering, and, very fortunately, through the generosity of Col. Albert A. Pope, a favorable opportunity is offered at this Institute, as funds are provided to do the work necessary to bring into suitable shape such a course of instruction.

Highway Engineering, at the outset, should be accepted as a branch of Civil Engineering, and it should be recognized clearly that a suitable foundation of preparation in civil engineering studies is

essential. It is as necessary that a knowledge of the specialty should rest upon a thorough grounding in engineering as it is that a load of Macadam's broken stone should have a suitable bed to rest on. Mud will not serve the purpose.

Leaving out of consideration the question of suitable general preparation, what should constitute the course of instruction in highway engineering proper? In beginning the treatment of roads it seems appropriate that some reference should be made to their importance, commercial, social, political and military; brief attention should be given to what is known of the earlier history of highways, of the existence of ancient roads in Mexico and Peru, and among the Egyptians and Carthaginians; of the Roman roads, some of which are still in use; of the older English roads, and the earlier inferior methods of repair, not dissimilar to what can be found in the back regions of our own country.

The early improvement of English roads was due largely to the efforts of Macadam and Telford, who were contemporaries; Macadam confining his attention to the improvement of the surface, while Telford, who was an engineer of prominence, was called upon for the broader duties of establishing systems of highways covering large sections of country, and of locating the roads to be included in the systems, as well as improving the surface. Even in the latter art Telford appears to have been the equal of Macadam. Our highway engineers should then be fitted to pursue the broader duties entrusted to Telford rather than confine themselves to the narrower field so admirably filled by Macadam in his day.

It is not improper that reference should be made very briefly to the earlier roads and highways of this country; the development of turnpike systems; the influence of canals, and the inauguration and growth of the railroad, the ideal highway. Attention may well be called to the fact that in this country the railroad enters new lands and develops new territory, the wagon road following to supplement the work of the railroad; while among the older nations the wagon roads commonly developed a section of country to a point where the advent of the railroad became a necessity; and that this difference of conditions has had its effect upon the quality of roads existing in the different countries. Our highway engineer, our future Telford, should be competent to mark out the main lines of highway needed to develop

any given section of country; he should have the requisite skill to locate them in detail; he ought to understand the principles of thorough and economical construction; he should be capable of supplying a suitable covering or wearing surface of road, and of maintaining it afterwards; and the instruction provided should be directed towards those ends.

It will be convenient for our purposes to make a distinction between roads and streets, although the two have many points in common. We may consider a road as a "track for travel, forming a communication between one city, town, or place, and another," this being Webster's definition; while a street may be defined as "a track for travel within a city or town." Then, taking up the subject of roads, we may investigate the requisites of a good road; first, as to its expense or economy; second, as to its shape or cross section; third, surface or finish; fourth, direction or alignment; fifth, grade or inclination.

It may be well to briefly explain what is meant by the item mentioned as "expense or economy." In connection with railroads it is customary to devote considerable attention at the present time to the subject of economic location, and the elements of economy which enter into the consideration are (a) cost of construction; (b) cost of maintenance; (c) cost of operating; (d) amount of revenue. A proper economy requires that the amount of revenue, less the sum of cost of operating, cost of maintenance, and interest on cost of construction, shall be as large as possible; this constituting the profit. The study of roads, their location and construction, should likewise include a proper consideration of the same elements. The problem is not the same in the case of roads as of railroads. With roads no revenue is received, except in the case of toll roads. The town or county, the owner of the road, does not operate it,—that is, does not haul the traffic. In spite of this, it is true, nevertheless, that the public, which uses or operates the road, pretty well represents the town or county which is the owner, and the public does in effect receive the toll which it is freed from paying, so that the same general principles closely apply, although there are not satisfactory data in the case of roads to allow any refinements of calculation. In the case of roads, as in the case of railroads, we can properly spend a large amount of money if this will cause a decrease in the annual cost of maintenance, or if a larger load can be drawn by a unit of power, or if a larger traffic will

be accommodated. It is important that these elements should enter into the consideration, and that the student should be led to appreciate their importance and be furnished with such data as are available, to aid him in forming a correct engineering judgment in such cases. With all modern engineering it has become essential that economy should be considered, as well as the safety and fitness of any structure for its intended purposes, and all engineering instruction should recognize the importance of the economic features.

In connection with the shape or cross-section there would naturally be considered the width, and this in general may be liberal for the total width, but should be narrow for the wagon road proper, inasmuch as money spent in unnecessary width could be better used in providing broken stone instead of gravel, or in graveling an additional length of earth road. The form of wagon way, too, is a question about which there exists a difference of opinion, some favoring a uniformly rounded section, while others prefer straight slopes on each side with very slight rounding at the center. The subject of *drainage* of the road may properly be considered in this connection, and very thorough attention should be given to it. There is no feature of road building more important than the drainage, and the whole subject may well be treated in detail, tile drainage as well as ditches receiving special attention.

The requisites as to surface or finish are that the surface shall be hard and smooth. The effect of protuberances may be considered, as well as the effect of a soft or yielding road. Very many experiments have been made upon the resistance to traction upon various qualities of surface, at various speeds, and with various kinds of vehicles, and the student should be furnished with a complete table of the results that have been reached, showing, among other things, by whom the experiments were made.

In the matter of direction or alignment attention should be called to the advantages possessed by straight roads for purposes of transportation as distinct from pleasure driving, and to the fact that for most purposes the straight road is preferred, unless distinct advantage from our standpoint of expense or economy will be secured by some deviation; and this consideration leads naturally and directly to the question of grade or inclination. While our knowledge of the resistance due to the hardness or softness of the surface is experimental and subject to

some uncertainty, the resistance due to grade can be determined with mathematical accuracy, and the combined effect of the two resistances should be studied, as well as the mathematics of grade resistance alone. It is found, too, that there are practical limits of grade, both maximum and minimum, beyond which especial disadvantages are encountered, the lower limit hinging on the question of drainage, and the higher limit being reached at a point where a wagon will slowly roll down hill by its own weight.

Having investigated the requisites of a good road, we are in position to discuss various matters connected with the subject, as follows: first, location; second, workmanship and materials; third, maintenance; and fourth, legislation.

It is considered advisable that the course in "Highway Engineering" should be allowed to follow rather than precede the study of Railroad Engineering. In such case the amount of time and attention given to the subject of *location* need not be as great as would otherwise be necessary. The principles would be essentially the same as those with which the student has already become familiar in connection with railroads. The reconnoissance, the preliminary, and the location surveys, will follow in the same order and be conducted upon the same basis, except that there will be a difference in some important details. For instance, very much sharper curves can be used upon highways than upon railroads. A curve of 50 feet radius upon a highway would in general be considered not more disadvantageous than a curve of 500 feet radius on a railroad. Again, for a short time a horse can exert several times the power that he can uniformly maintain, and the application of the principle of maximum grade will thus be somewhat different. The instruction in location, therefore, can be confined mainly to a description of the difference between the work of railroad location and that of highway location, although examples of highway location should be shown, and problems in contour location given the student, to be worked out in detail. The subject of location is regarded as important and not to be treated lightly, although the time required will be small after railroad location is well understood.

Under the head of workmanship and materials, we are brought directly to the subject of construction, and the student should have his attention called, here or elsewhere, to certain steps that are

necessary previous to construction: the procuring of land and the methods by which it may be secured; something of the essentials of deeds; what is meant by the Right of Eminent Domain,—what it is, and in what cases it may be made use of; together with some other matters of a similar sort. It is possible that engineers have been too apt to confine their attention solely to engineering features, and have failed to consider legal difficulties, which of right often enter into the engineering problem; and a brief reference to the above points as well as to the essentials of a contract would prove a very useful part of the course of instruction.

Construction proper would lead to a discussion of the methods of conducting the work of excavation and embankment,—by scraper, by cart, by wagon, or by the road-grading machines which have been successfully used in many places. The advantages of a road built in horizontal layers can be pointed out; then come methods of preventing slips on side hills by cutting the foundation into steps, or by the use of retaining walls, although the latter have application for other purposes than that mentioned. In this connection, merely as a measure of economy, some of the time that would otherwise be necessary for this purpose can be saved by preparing and providing drawings illustrating the different methods of sustaining embankments or the sides of cuts, which have been used in this country and abroad, so that the student may be provided with a fund of information in the shape of drawings, to which he may refer from time to time, when difficulties present themselves to him in his practice after graduation. There are many other structures to which the student's attention should be called, such as culverts and bridges, for the purpose of crossing streams or railroads, and here again a set of drawings representing different types of structure can hardly fail to prove of great value, as a working outfit adapted to future practice. The instruction in the details of such structures would form properly a part of a course in bridge construction, except so far as the preparation of the roadway surface is concerned. It is believed that insufficient attention has been paid heretofore to the preparation of the roadway surface of highway bridges.

In the consideration of roads and pavements, the road-covering or surface has usually attracted the most attention, and probably in many cases more than its fair share; a failure to under-drain a road

may render it difficult or impossible to maintain a satisfactory surface. The road-covering, or surface of roads (as distinguished from streets), should be taken up in detail, and may be conveniently treated in the following order: first, earth; second, corduroy, plank, and charcoal; third, gravel; fourth, miscellaneous; fifth, Macadam; sixth, Telford; seventh, Macadam and Telford modified; while the consideration of pavements may be postponed until the subject of streets is reached. The subject of earth roads is to receive more than passing attention. If it be possible by drainage, by rolling, or in any thoroughly inexpensive way to greatly improve the earth roads, which are the prevailing roads in the United States, a vast amount of good must result from it. It should be the aim of the instructor to gain, in every way possible, data touching the improvement of the ordinary earth road by means less expensive than the addition of gravel or broken stone. A serious difficulty in securing good roads exists in the fact that many communities feel themselves unable to incur the expense necessary to produce even a good gravel road.

In this immediate neighborhood the corduroy, plank, and charcoal roads are matters of no great interest, but in many sections of this country they have been found useful, and have served their purpose well; and, as a young engineer is something of a migratory animal, it is proper that he should have a brief introduction to these forms of road. When something better than the ordinary earth road is required, recourse is generally had to the gravel road, and gravel roads may be found in abundance through the villages and towns of New England, as well as in the minor streets of many cities. There are different methods of applying gravel; there are different qualities of gravel to be applied. Sometimes, as in Central Park, the gravel is laid on a foundation of stones on edge, substantially the Telford foundation; and not only should the student be well informed as to these matters, but he should also be provided, as before, with drawings, showing the cross-section and construction of existing roads, and of standards recommended. Before passing to broken-stone roads, the miscellaneous class can properly be touched upon. It includes various constructions of occasional, special, or local availability, such as the use of shells, coal slack, or furnace cinders.

For the *ordinary* highway the practical perfection of road surface at the present time may be considered to be the broken-stone road,

whether in the form of Macadam or of Telford road. The student should be made acquainted with the exact processes and principles of Macadam's construction, the size of stone, the method of breaking, the method of compacting, the precautions to be taken, the special methods of use, and applications under various circumstances. The Telford road can well be described by calling attention to the points in which it differs from the Macadam road. The original specifications as drawn by Telford are available and should be furnished the student. The requisites for a broken-stone road should be carefully investigated, also the quality of material of stone to be sought for; and particular directions given how to proceed to secure this in actual practice. Methods of testing can be described, and an opportunity should be given for the students themselves to conduct such tests. Apparatus specially adapted for such purpose should be provided. By a grinding wheel the wear of a standard specimen and of the stone to be tested can be determined, the comparative loss of weight measuring the ability to resist wear. This method of testing is, however, better adapted for paving blocks than for broken stone. For the latter, a better method is to enclose specimens to be tested in one cylinder, the standard specimens in a second cylinder, together with iron castings, an equal amount in each case, and after revolving the cylinders for a given length of time, and through an equal number of revolutions, to observe the loss of weight in the test specimens as compared with the standard. The test for the action of weather has often been made by the use of sulphate of soda, not altogether successfully, and it seems reasonable to suppose that more satisfactory results can, at the present time, be reached by taking advantage of the fact that apparatus for artificial freezing is in constant use throughout the year in Boston, and probably in many other cities of the country. The ordinary testing machines can be brought into use to measure the resistance to crushing. The student should be made to understand that all artificial tests are imperfect when compared with the perfect test of trial in the road, but that as a preliminary, and in connection with the actual test, the artificial tests should prove of practical as well as scientific value. It should be understood, of course, that with suitable apparatus provided, and with tests conducted, not alone for the students' benefit, but also in connection with work in progress, results of not a little scientific value would gradually and in time be secured.

Little has been done in this country, up to the present time, in the direction of testing road materials. French engineers have, however, acquired considerable useful data of this sort, and there would appear to be no reason why such data should not be made available for compilation with any results obtained in this country.

The student's attention should be called to the different methods of stone breaking; to the superior quality of stone cracked by hand over that crushed by machine, although the latter is commonly used on account of its lower cost; to the cost of the stone broken in different ways; to the advantages and relative freedom from repair of the different kinds of crusher; and to the arrangement of the stone-crushing plant in order to avoid rehandling material, and thus secure increased economy. An excursion to a stone crusher in operation will make clear many points that any attempt at description would fail to reach.

When the student well understands the Macadam and Telford roads, strictly considered, it will be proper that his attention should be called to the modifications of Macadam and Telford road that are common in this country; to the fact that little or no pure "Macadam" road is now laid, because it is found better to use screenings from the stone crusher, or some other binding material to cover the broken stone previous to the final rolling, while Macadam was strenuous in his objection to the use of any binding material whatever. The difference between the original Telford and the present Telford roads is less marked, the arrangement of the layers of different sizes of stone being the principal feature, if we except the difference in the method used for compacting the road material. Some notice also should be taken of other methods of laying the foundation stones, since some advocate laying the stone flat instead of on edge. It is believed to be important that the student should be informed of bad methods of work in order that he may avoid them, as well as of good methods that he may adopt them. It is possible that Macadam's objection to the use of binding material may have been proper when the road must of necessity be compacted by traffic rather than by rolling, for road-rollers were not used in Macadam's time, horse rollers coming into use in England about 1840 and steam rollers somewhat later than 1860. We are thus naturally led to the consideration of the subject of road rolling, an important subject which deserves and should receive some-

thing more than passing notice. The disadvantages of traffic compacting should be dwelt upon somewhat in detail; as being cruel to horses, obstructive to traffic, ruinous to vehicles, wasteful in its wear of the broken stones, as well as objectionable in other features, while experiments made in this country and elsewhere can be cited to show that the main advantage in rolling is that the road wears better. It can be shown, as the result of experiments, that better wearing roads are secured by steam rolling rather than horse rolling, and by horse rolling rather than traffic compacting. Different forms of rollers can be described and photographs exhibited to better illustrate them, while opportunities are afforded from time to time in any large city to see them in action. The subjects of rolling and the use of binding material are properly discussed together, and there are differences of opinion among competent engineers as to the quality of binding material to be used, while an occasional doubt is expressed as to the advantage of steam rolling. In connection with broken-stone roads, drawings showing the arrangement and thickness of typical roads actually existing should be prepared, and it would probably be of advantage to provide, in suitable boxes with glass fronts, samples of broken stone arranged in the proper way to illustrate the Macadam and Telford, as well as later American roads. The subject of country roads should receive very careful consideration, and data as to the cost of various kinds of surface should be compiled, since a serious obstacle to the improvement of country roads lies in the expense necessary for their construction.

The subject of streets should next receive attention, and we should study, to begin with, methods of laying out cities. Boston certainly is not a good example to follow, nor is a rigid adherence to the rectangular system desirable, although this is the system very largely adopted. The student's attention should be directed to the radiating system combined with rectangular, well illustrated in Washington and Indianapolis, maps of which cities should be exhibited. The requirements of drainage should be considered, the streets arranged with reference to the contour of the surface, and the student cautioned against any rigid rule that should in all cases lead to the adoption of true north and south lines and true east and west lines for the directions of the streets. Some foresight as to the necessity for sewers, water and gas mains, will often result in providing alleys of liberal

width and suitably arranged, so that the greater part of these underground structures shall be carried through the alleys rather than in the streets, which can thus be kept in good condition. In this way it is possible to avoid the very serious difficulty which results from disturbances of the streets necessary for renewals or occasional repairs of the pipes or sewers.

It is evident, then, that the municipal or highway engineer who is called upon to lay out a city should be something more than a surveyor,—should be something more than a road builder; he must almost of necessity depend, to a considerable extent, upon a broad and general foundation in civil engineering. The student should have his attention called to the bearing upon this subject of his instruction in surveying, in topography, and in sanitary and hydraulic engineering, as has previously been done as to the bearing of railroad engineering, of bridge engineering, and of the theory of structures, in connection with location, highway bridges, and retaining walls. Some instruction should be given as to the best method of fixing and defining the grades and lines of streets, and drawings should be provided illustrating these methods and furnishing samples for guidance as to the proper style to be used in making office plans. Various interesting problems occur in connection with the street grades. An instance is when the two curbs are at different levels, and more particularly at the intersection of two streets, one or both of which have steep grades. At this time, too, it is not inappropriate to call attention to the excellent practice prevailing in some cities, of making the side slopes steeper when the longitudinal slope is greater, in order to carry the water more promptly to the gutters.

The *surface* of streets should next be considered in detail. The materials for the surface would include most of those used for roads, together with various others, such as cobble-stone, stone block or Belgian, wood, brick, asphalt, tar concrete, cement concrete, and some miscellaneous materials. Before describing the different kinds of pavements, it is proper that we should understand what are the requisites for a city pavement. For instance, it is desirable that the pavement should be smooth, though affording a good foot-hold for horses, free from mud and dust, noiseless, water-tight, readily cleansed, easy to re-lay satisfactorily, as well as inexpensive in first cost and in maintenance. While no known pavement fully satisfies all these condi-

tions, yet nearly every kind of pavement has some advantages, and the student should be made acquainted with the good features of even those pavements which are generally regarded as inferior, and with the objectionable features of those most favored. For example, the old-fashioned cobble-stone pavement is passing out of general use and the stones sent to the crusher to be broken up, yet it is regarded by street-railroad managers as superior to all others for paving between tracks, on account of the foothold afforded to horses. Among its inferior qualities the roughness for traction may be mentioned as among the reasons which have led to its falling into disuse. Something of the same sort may be said as to the rubble-stone pavement. A consideration of gravel and broken-stone roads will show that they afford considerable mud and dust, and in many ways fail to meet the requirements, although for general driving, or for park purposes, they are still regarded as superior in spite of their imperfections. Considerably more extended notice may be taken of the stone block or Belgian pavements, inasmuch as there are many varieties, the stones varying noticeably in size and quality; and it may be well to trace the progress, or the changes made in the stone-block pavement used at different periods, and the causes of these changes. Attention can be called to the quality of material that it is ordinarily desirable to use; and there is no good reason why samples of clean, washed gravel, and of gravel having foreign material mixed with it, should not be shown the students to give them a clearer idea than would be reached from mere description. The method of laying the stones at street intersections, where the herring-bone fashion is sometimes used, may form the subject of a description and of drawings as well. Some reference should be made to those abnormal arrangements of blocks where the even surface is not maintained, but the stones are laid with the joints inclined in order to give better foot-hold, as well as to other methods in which the rectangular section of block is not maintained. The student should especially have his attention called to the fact that modern highway engineering is disposed to regard the body of the road as composed of two principal essential parts, the foundation and the wearing surface; that the quality of foundation may vary from ordinary earth well prepared upon the one hand to a layer of concrete on the other, present practice inclining to cement concrete for heavy traffic. The wearing surface used may be of any of the materials, except earth,

that have been mentioned,—gravel, broken stone, stone pavement, wood, brick, or asphalt. While there are a few examples about Boston of stone-block pavement with concrete foundation, a description should be given of the very superior pavement which has been used in London with great success, and with equal success in some of our American cities, in which the foundation is a layer of about 6" of concrete, while the wearing surface is composed of stone blocks, carefully laid, the joints filled with a mixture of pitch tar and what is called creosote oil, forming a cementing substance which renders the joints water tight, and gives the pavement almost a monolithic character. It should be pointed out, too, that the ease of traction that has followed this construction must be due to the evenness of fracture in the paving blocks as well as to the method of putting them together.

Neither will it do to neglect the claims of wood pavement, although this has come almost absolutely into disuse in the East. In some parts of the West, wood pavement is now used very extensively in spite of the fact that it decays quickly and wears out in a few years; but the student should be led to see that a pavement which can be put down for 80 cents per yard can be replaced after a few years with no greater cost in the aggregate than a more durable permanent pavement, which would cost \$4 or upwards per yard. The experience in the use of preservative processes for wood pavement can profitably be recited, and the various forms, patented or otherwise, which have been used for wood pavements can be shown to advantage by a series of drawings. The *sanitary* features should, of course, be spoken of in connection with the subject, as well as the means adopted to overcome the difficulties incident to the swelling and shrinking of the wood due to the presence or absence of moisture. Another form of pavement used very little in New England should receive considerable attention; this is brick pavement, which is quite largely used in some parts of the South and among the Western cities. The many good qualities which recommend it should be mentioned, as well as the objections, the most important of which at present appears to be the difficulty of securing bricks of even quality and sufficiently hard and tough to serve the purpose. A compilation of the results of various tests of paving bricks would prove of value, and it would probably be well to gather statistics as to success or failure and the attending conditions, by inquiry of the city engineers of those cities

which are known to have used brick pavement. There would appear to be no other means of determining the value of this kind of pavement, because the experience has not been uniform, many engineers having used it very successfully, while in other cases results have not been satisfactory. The brick pavement in Winter Street, Boston, which lasted only about two years, is a case in point.

The various forms of asphalt pavement should be next described, and asphalt distinguished from tar concrete. The methods of preparation of the asphaltic cement can be explained, as well as the difference between natural asphaltic rock and the asphaltic cement just referred to, prepared perhaps from Trinidad asphalt. It is not proper that the subject of asphalt pavements should be treated otherwise than fully, as probably the finest paved streets in the country have asphalt surfaces, while the opportunity afforded for an instructive and interesting lecture on this subject will readily be conceded by those who were fortunate enough to listen to Captain Greene's paper before this Society a year or more ago.

A careful comparison of the different qualities of pavement described has been made by boards of experts, while many special committees of cities have rendered reports upon the same subject, so that there is considerable material as to the comparative merits of the different pavements, and this can be placed before the students, in addition to such criticism as the instructor may himself see fit to make.

The facts that asphalt is expensive and in wet weather slippery; that wood is perishable and absorbs impurities; that granite blocks are very noisy and less favorable to traction, give ample opportunity to compare the merits of various classes of pavements, with a resulting conclusion perhaps that no single pavement is superior under all conditions, and that a knowledge of the good and bad special features of each will allow engineering judgment to reach proper results in most cases. Statistics as to cost can without difficulty be compiled, and although the conditions prevailing in different cities would affect these somewhat, the results obtained should prove of interest and value.

The very important subject of maintenance of roads and streets should perhaps be left until this time, although it is possible that it may be taken up to better advantage somewhat earlier. There is no doubt very much in relation to the maintenance of roads that can be learned only by experience, and perhaps less of detail can profitably be

taught in this connection than in connection with the construction of roads. Nevertheless, there are many matters of principle, and some matters of detail, that should certainly be alluded to. It is probable that the worst defects in many of our American roads are due to inferior methods of maintenance. It is claimed by some of our best American road engineers that in the construction of broken-stone roads we are in no degree inferior in ability to the French or English, but it is doubtful if an equally favorable claim would be made as regards maintenance. It is probable that from the French we may secure the best information as to systems of maintenance, although without question there can be obtained from English engineers and road builders much data in detail that would be of great advantage to us. The claim as to the excellence of construction in this country refers, of course, only to the best constructed roads. Of the inferiority of the average American road there can be little doubt. How much instruction should be devoted to the subject of maintenance, and just what should be the character of that instruction, can better be determined after a more careful study of the methods in force in foreign countries than the writer has been able to give to the subject previous to this time. How satisfactory the results have been from the subdivision of the roads into sections, each under the charge of a road supervisor, would be a proper matter to determine and bring to the attention of the student; the amount of water to be used in sprinkling, and the number of sprinklings per day; whether the road should have fine stuff added to it as soon as any appearance of wear occurs, or whether the road should be left until a patch of more substantial matter can be added,—these are proper matters for discussion about which there are some differences of opinion. Unquestionably, much water in sprinkling tends to noticeably soften and weaken the material.

Another question which has in general received too little attention, certainly in the few text books which exist on the subject, is that of sidewalks, foot-paths, curbing, and the paving of gutters, which form essential and important parts of the street. The student should be informed regarding the various kinds of material that can be used for sidewalks. Tar concrete, asphalt, and gravel are common to both sidewalk and road, while ordinary brick, stone flagging, and artificial stone, of which Portland cement forms a part, are used only in con-

nection with sidewalks. The merits of the different materials, and the comparative expense, will certainly prove of interest. It would prove advantageous to collect specimens, not only of different kinds of sidewalk material, but of the various qualities of stone, brick, asphalt, and other material used in street paving.

There remains, then, the subject of road legislation; and in connection with this subject it would be well to make some reference to the system of tolls, under which very many roads in this country were first constructed. In some parts of the United States toll roads are by no means infrequent at the present time, almost within the limits of cities of considerable size. The evil results from the system of working out the road tax have attracted a good deal of attention, and should be spoken of.

Some notice should be given to the efforts made and the laws proposed for adoption by the legislatures of Massachusetts, Pennsylvania, Tennessee, and other States where the subject has received special attention. Another subject in connection with roads that has occupied the attention of the law makers is the safety of highway bridges. Legislation on this subject is a matter of extreme difficulty, and it is easy to frame laws, and perhaps pass them, which are likely to prove of only questionable utility. A word of caution and the enunciation of certain principles that should not be violated in any such law may prove of value not merely to the student but to the State.

The course of instruction which has been outlined and illustrated may be said to form the skeleton, which it is proposed shall be clothed with flesh, and which will then constitute the course in highway engineering at the Massachusetts Institute of Technology. It should not be understood that no instruction of this character has heretofore been given at the Institute. Such is far from being the fact. The outline which is shown above may be considered as the outgrowth of the course of instruction which has already been given at the Institute. The course, however, is being amplified and perfected in many ways, at least twice the amount of time previously available being considered proper to be devoted to the subject, owing to its increasing importance. Through the generosity of Col. Albert A. Pope it has become possible to provide special apparatus, and to gather and arrange specimens, materials, and drawings, that would otherwise have been, for a time

at least, beyond our reach. Neither should it be assumed that the course which we have held in view is incapable of improvement and development. New opportunities for effective instruction will suggest themselves from time to time, and a general development from year to year can be considered as the almost certain outcome.

In addition to what has already been mentioned, it is proposed to supplement the systematic instruction by occasional lectures delivered by practicing engineers who have made a specialty of highway engineering.

There has already been found to be an increasing demand for municipal engineers, among whose most important duties should be the care of the highways. The demand for better highways, and for highway engineers, it is believed, fully justifies the special attention that is proposed to be given to this Course of Instruction in Highway Engineering.

MEETING 411:

Aluminum.

BY MR. ALFRED E. HUNT.

The 411th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, February 12th, at 8 P.M., President Walker in the chair.

After the reading of the records of the previous meeting and the election of members, the President introduced Mr. Alfred E. Hunt, President of the Pittsburgh Reduction Company, who read a paper on "Aluminum."

Mr. HUNT said: The metal aluminum has certainly not been "damned by faint praise." On the contrary, from my experience as the president of an aluminum manufacturing company which has been endeavoring for the past two years and over to sell the commercially pure metals in the markets, and to introduce it into the arts and manufactures of the country, I have to state to you as my conviction

that one of the two chief difficulties encountered, and which today retards and restricts the wider use of the metal, is the extravagant, erroneous, and in many cases mischievously misleading, statements which have been made as to the properties of the metal, which have received wide circulation, not only through the daily newspapers, but, I am sorry to add, through many technical and scientific journals as well. The other difficulty is the almost equally widespread, and, so far, equally extravagant and misleading, series of claims made by the inventors of processes for the manufacture of aluminum at remarkably low prices.

I shall endeavor in this lecture to correct some of these fallacies as to the properties of the metal, and also, in describing the minerals in which the metal occurs and the methods of reduction which have been practiced, to explain the principal difficulties which have thus far been encountered. I shall also venture a prophecy as to the success of cheaper methods of manufacture of aluminum in the future.

Some of the erroneous statements regarding aluminum have had their origin in the fact that commercial aluminum is never chemically pure, and that until within the past eight years nearly all the aluminum of which the properties had been described had at least 4 per cent — in many cases 6 or 8 per cent — of impurities. These materially altered the characteristics from those of the purer metal, with not over 2 or at most 3 per cent of impurities, which is ordinarily sold in the markets today.

The impurities almost always found in aluminum are silicon and iron. These two impurities are almost the only ones found in the electrolytically deposited metal, considerable amounts of any others being accidental and due to carelessness in manufacture. In fact, I hope to be able in the near future to say that the impurity consists of the single one silicon, as we have already made many hundred pounds of aluminum, with only a trace of iron present, and tons of metal with less than $\frac{1}{10}$ of 1 per cent of iron.

The silicon present in aluminum exists in two forms, one seemingly combined with the aluminum, as combined carbon exists in white pig iron, and the other in an allotropic graphitoidal modification. These two forms of silicon seem to exert somewhat different effects by their presence in the aluminum, the combined form of the element rendering the metal much harder than the graphitoidal variety. The

combined silicon ordinarily preponderates, being from 55 to 80 per cent of the total silicon in the average metal of between 98 and 99 per cent purity made by the Pittsburgh Reduction Company.

For many purposes the purest aluminum cannot be so advantageously used as that containing 3 or even 4 per cent of impurity, as the pure metal is very soft and not so strong as the less pure. It is only where extreme malleability, ductility, sonorousness, or non-corrodibility is required that the purest metal should be chosen. We shall probably find that for most purposes a small percentage of other elements than silicon and iron are advantageously added in producing hardness, rigidity, and strength,—constituents that will not detract from the non-corrodibility of the metal as much as do these natural impurities that come from the ore and apparatus,—additions that will give the aluminum a better color and greater strength and hardness with proportionately less sacrifice of malleability, ductility, etc.

Pure aluminum is white, with a decided bluish tint. This becomes much more marked upon exposure, when a thin film of white oxide on its surface prevents further tarnishing from the air, but seems to give, by contrast to the metal as a background, an enhanced bluish tint. I am sorry to hear my good wife report this color as giving a decidedly pewtery appearance to the spoons and forks which we have had in almost constant daily use, for comparison with silver, during the past year and a half. The oxide which gives this decided blue tint may be removed by immersion in a dilute solution of hydrofluoric acid, and then rubbing with chamois skin saturated with petroleum.

No one should expect the color of silver in aluminum,—especially of silver of the markets, which is given a decided yellow tinge with copper; for the natural color of aluminum is different, and the addition of copper, although making the metal a yellower white, does not entirely change its natural bluish-white tint. The addition of small percentages of silver, chromium, manganese, wolfram, or titanium, undoubtedly improves the color of aluminum, making it nearer to that of silver.

Aluminum melts at about 1300° F., but becomes pasty at a temperature of about 1000° F., and indeed loses its tensile strength and very much of its rigidity at a temperature of 400° to 500° F., although this loss of strength is only while the metal is kept at the high tempera-

ture. It serves as an annealing operation, and reduces permanently only the higher tensile strength produced by cold rolling or otherwise cold working the metal. Aluminum does not volatilize at any temperature ordinarily produced by the combustion of carbon, even though the high temperature be kept up for a considerable number of hours. It, however, absorbs a very large amount of occluded gases under such treatment. In the high temperature of the electric furnace, it is claimed that there is considerable volatilization of aluminum, and that small buttons of the metal have been found in and on the linings of the furnace. The Cowles people, however, have never been enabled to collect and commercially produce pure aluminum by their electric furnace, for the reason that the metal rapidly oxidizes into alumina. It has only been by protecting the reduced metal with an alloy of either iron or copper that they have succeeded at all in retaining the reduced aluminum.

Under heat, the coefficient of linear expansion of $\frac{3}{8}$ in. round aluminum rods of 98.50 per cent purity is .0000206 per degree centigrade between the freezing and boiling points of water; that of iron being .0000122, tin .0000217, copper .000017182. Multiplying this factor by $\frac{4}{9}$ to reduce it to the Fahrenheit scale, we have .0000115, or an expansion of .00115 ft. on 100 ft. of aluminum raised 1° F. from 32°. It is probable that the coefficient of expansion of alloys of aluminum is very close to that of tin.

The specific heat of aluminum is 0.2143, water being taken as 1. The metal follows the general rule of metals, its specific heat being inversely as the atomic weight.

By the method of Weidemann and Franz, taking silver as 100 and copper as 73.6, unannealed aluminum of 98.50 per cent purity has a coefficient of thermal conductivity of 37.96; and the same wire annealed, 38.87. In the same scale tin has a heat conductivity of only 14.50, iron 11.90, steel 11.60, and lead 8.50. From this it is evident that, next to silver, copper, and gold, soft annealed aluminum is the best conductor of heat.

It also stands next to silver, copper, and gold as a conductor of electricity. One yard of annealed aluminum wire of 98.50 per cent purity, .0325 inch in diameter, at 14° C., has .05484 of an ohm resistance, a yard of pure copper wire of same section having a resistance of .0315 of an ohm. The electrical conductivity of silver being

taken at 100, and copper at 90, pure annealed aluminum has an electrical conductivity of about 50. These facts, taken into consideration with the lightness of the metal as compared with silver, gold, and copper, are already leading to a quite extensive use of aluminum in electrical apparatus.

Pure aluminum, and indeed the electrolytically made commercial aluminum, with less than $\frac{1}{2}$ of 1 per cent iron, regularly put upon the market today, exhibits no appreciable polarity. Such metal has many advantages for compass boxes, or for cases for electrical apparatus where non-magnetic properties are desired.

The fracture of aluminum shows ordinarily hexagonal crystals, although the pure metal is very tough, and in breaking, by bending backward and forward, often appears distinctly fibrous in fracture. The lack of rigidity and hardness which the metal exhibits is a serious obstacle to its adaptability for many purposes, although both stiffness and hardness are very much increased by the addition of a few per cent of impurities or alloy, and are especially improved by cold-hammering, cold-rolling, drop-forging, or the like. For castings for surveying instruments, pure aluminum would be especially adapted were it not for its softness and lack of rigidity. It can be safely stated as a general rule that the purer the aluminum the softer and less rigid it is.

Pure aluminum is, when properly treated, a very malleable and ductile metal. It can readily be rolled into sheets $\frac{1}{10000}$ in. thick, or be beaten into leaf nearly as thin as gold leaf, or be drawn into the finest of wire. Pure aluminum stands third in the order of malleability, being exceeded only by gold and silver; and in the order of ductility seventh, being exceeded by gold, silver, platinum, iron, softest steel, and copper. Both malleability and ductility are greatly impaired by the presence of the two common impurities, silicon and iron.

Aluminum can be rolled or hammered cold, but the metal is most malleable at between 200° and 300° F., and should be heated to this point for rolling or breaking down from the ingot to the best advantage, and even then considerable power is required, fully as much as for hot-rolling of hard steel of similar section, although not nearly as much draft can be placed upon the rolls as in hot-rolling hard steel. Like silver and gold, aluminum stiffens up remarkably by working it, increasing a great deal its hardness and its tensile strength, and decreas-

ing its malleability and ductility; it requires to be frequently annealed. As compared with cold-rolling soft steel, it has been found practicable to give aluminum about the same reduction in each pass as the steel, the aluminum requiring on the average five annealings where the steel requires but three.

By hardening the metal by rolling, forging, drop-forging, stamping, drawing, etc., it may be turned out very rigid, and will then answer excellently for purposes where the annealed metal would be entirely too soft, too weak, or lacking in rigidity or elasticity. Especially is this true of aluminum alloyed with a few per cent of titanium, copper, iron, silicon, or the like. The alloys do not show their increased hardness to anything like their maximum extent in castings, and, I am sorry to say, not at all in proportion to the increased brittleness. But when these castings are drop-forged, rolled, hammered, or drawn down, with only sufficiently frequent annealings to prevent the metal from cracking, the increased hardness shows up in a remarkable degree. These properties have already become not only the subject of a considerable number of letters patent, but also of established uses in the arts, and will, in future, add enormously to the applicability of the metal.

To anneal aluminum, a low and even temperature should be maintained in the muffle,—just such a temperature as will show an even, red heat in a piece of iron or steel placed in the muffle when viewed at twilight or on a dark day. The aluminum itself, however, should not appear at all red at this temperature. A ready test of this temperature is that the metal has been heated enough to char the end of a pine stick, which will leave a black mark on the plate as it is drawn across it. When the metal has acquired this temperature, it should be taken from the furnace and allowed to cool gradually. Very thin sections may be annealed by placing into boiling water, and either allowing to cool with the water or taking out to cool gradually. Of course, it is possible to anneal to any degree by lowering the temperature to which the metal is heated below that specified by means of suitable appliances.

Aluminum can be easily and readily welded by the apparatus of the Thomson Electric Welding Company.

Until very lately the lack of methods for successfully soldering and hardening aluminum were two of the greatest drawbacks to its

introduction for many purposes. I am glad to be able to say to you, however, that both of these difficulties, I believe, have lately been successfully overcome. I have already outlined to you the method of alloying pure aluminum with a few per cent of hardening metal, and cold-rolling or otherwise working, as being ways out of the difficulty of its softness. The exhibitions of soldered metal will show you that aluminum can now be successfully soldered. These results were obtained by the use of the blow-pipe and with ordinary hard or soft solder, or with pure zinc, or with an alloy of zinc and aluminum, as the soldering metal. The novelty, which has just been covered by letters patent in one successful case, is in the soldering salt, which allows the solder to flow freely on the surfaces to be united.

Sound castings of aluminum can be readily made in dry sand molds. The aluminum should not be heated very much beyond the melting point; otherwise it seems to absorb gases, which remain in the metal, preventing sound castings. In small quantities the metal can be best melted in plumbago crucibles; but in large quantities it can be more economically melted in a reverberatory furnace with alumina or magnesia brick sides and alumina bottom. The furnace should have a tap-hole for drawing off the liquid metal into carbon-lined ladles. In no case need the metal be covered with a flux to assist in the fusion or to form a covering of slag. In fact, owing to the metal's lightness, the presence of any flux will tend to unsoundness, due to particles of it becoming entangled in the castings, while impurities may perhaps be added to the metal by the action of the flux on the lining of the melting vessel. The molten metal flows readily, and not much larger gates are needed than for brass. The shrinkage of $\frac{1}{4}$ in. per ft., which aluminum has, is considerably more than that of brass, which is about $\frac{3}{8}$ in. per ft. The shrinkage can be reckoned ordinarily as about 2.26 per cent of the length of the mold. Wooden patterns made for brass, to give equivalent castings of aluminum, should be given three or four thick coatings of shellac.

As to the corrodibility of aluminum, a great deal has been printed that is not correct. In the first place, aluminum is acted upon by the atmosphere, especially by moist atmosphere, and more especially still by moist salt atmosphere. The metal becomes covered by a very thin, almost imponderable, coating of oxide on the surface exposed to the atmosphere, which seems to protect it from further oxidation.

This coating is so thin as often to hardly interfere with any polish, and it does not materially change the weight of the metal. It does, however, increase the bluish tint of the metal, as before explained, and gives it a leadish color. As compared with most metals, pure aluminum, under ordinary circumstances, withstands the action of wind and weather exceedingly well; and many uses to which the metal is now being successfully applied are based upon this fact. The presence of silicon in aluminum materially detracts from its power to withstand corrosion due to atmospheric influences. Metal with 4 or 5 per cent of silicon very soon collects a thick coating of oxide upon it, if severely exposed. The fact that pure aluminum is not acted upon by boiling water or by steam has led to its use as a packing or gasket in steam connections, where lead and similar metals have been rapidly cut out (especially where the water contained notable amounts of sulphur acids), as in parts of steam and water pumps and difficult steam joints. The New York Steam Company have found it a very satisfactory way of packing their leaky steam joints to put in first a layer of aluminum wire, without attempting to calk it much, adding another ring of the softer, but more easily corroded, lead on the outside, which can be calked into place, making the joint steam-tight.

Aluminum containing sodium is rapidly acted upon by hot water, the sodium being eaten out, leaving the aluminum spongy and porous. Aluminum is unaffected by either concentrated sulphuric or nitric acids. Unfortunately, however, these commercial acids almost always contain some little hydrochloric acid, which rapidly corrodes the aluminum, the chloride of aluminum first formed being changed into sulphate or nitrate, the free hydrochloric again acting more violently as it attacks the metal in a nascent state.

Aluminum is not acted upon by carbonic acid, or carbonic oxide gases, nor by sulphureted hydrogen except at a red heat; but it is a peculiarity of the metal in a melted condition to absorb large quantities of these gases, quite a portion of which is again excluded as the metal cools. But enough is left in the case of the sulphide to emit strong odors of the sulphureted hydrogen which has been occluded and imprisoned in the metal in cooling. This fact is a strong obstacle to a sulphide method of reduction of the metal, where the sulphureted hydrogen evolved would strongly impregnate the metal for a long time, even after several meltings.

Pure aluminum has neither taste nor odor, nor is it corroded by any substances ordinarily used in culinary operations, and it seems, therefore, especially adapted for cooking utensils. For spoons, forks, and large dishes, the metal also is useful, although its color can be improved, and the metal made more rigid, by a slight addition of copper.

Aluminum is less acted upon than is tin or copper or silver by salt water, and even by such solutions in vinegar as the metal is liable to be subjected to in ordinary culinary vessels. The salts of tin or copper thus dissolved are very poisonous; but not only are the aluminum salts that are formed less in amount, but the acetate of aluminum formed resolves itself on boiling into either an insoluble sub-acetate or into pure alumina, neither salt having either taste or injurious toxic action. For these reasons, quite surely aluminum will have a large future for cooking utensils. A cooking skillet of aluminum has been in service for a year in my own household.

Aluminum is found to withstand the action of organic secretions better even than silver, and for many forms of surgical instruments, tracheometer tubes, suture wires, and the like, and for forms for holding false teeth, the metal is already receiving very wide use. Many surgeons are having their instrument cases made of aluminum, it having the advantage that they can safely be washed clean with antiseptic solutions. It may be well for me to say here, however, that perspiration in handling polished aluminum does tarnish the metal, and that aluminum, like other metals, cannot retain a high polish with frequent handling. The natural acid solvent for aluminum is hydrochloric acid. Solutions of the caustic alkalies, chlorine, bromine, iodine, and fluorine rapidly corrode aluminum. Ammonia gas has very little action on the metal, except to turn it a gray color. Strong aqua-ammonia has a slight solvent action upon it.

The specific gravity of aluminum, of course, is one of its most striking properties,—a property on which many brilliant “castles in the air” have been built. It runs from 2.56 to 2.70; structural steel is 2.95 times as heavy, copper 3.60 times, ordinary high brass 3.45 times, nickel 3.50 times, silver 4 times, lead 4.80 times, gold 7.70 times, and platinum 8.60 times as heavy.

Pure aluminum is very sonorous, and varying qualities of sound are given by its different alloys. Unfortunately, just the right shape

for an aluminum bell has not yet been discovered. The ordinary forms give out anything but an agreeable sound.

Cast aluminum has about the ultimate strength of cast iron in tension, but under compression it is comparatively weak.

The following table gives the average results of many tests of aluminum, having about the following composition: Aluminium, 97 to 99 per cent; silicon graphitic, 0.10 to 1 per cent; silicon, combined, 0.90 to 2.80 per cent; iron, 0.04 to 0.20 per cent.

Tension tests.	Castings.	Sheet.	Wire.	Bars.
Elastic limit per sq. in., lbs.	6,500	12,000	16,000 to 30,000	14,000
Ultimate strength per sq. in., lbs.	15,000	24,000	30,000 to 60,000	28,000
Reduction of area	15%	35%	60%	40%

Compression tests (in cylinders with length twice the diameter):

Elastic limit per sq. in.	3,500 lbs.
Ultimate strength per sq. in.	13,000 lbs.

The modulus of elasticity of cast aluminum is about eleven million; cold drawn aluminum wire, about nineteen million; aluminum sheets, about thirteen million.

Under transverse test pure aluminum is not a very rigid metal. An inch square bar of good cast iron, supported on knife edges 4 ft. 6 ins. apart and loaded in center, will readily stand 500 lbs. without a deflection of over 2 ins. A similar bar of aluminum would deflect over 2 ins. with a weight of 250 lbs., although the aluminum bar would bend nearly double before breaking, while the cast-iron bar will ordinarily break before the deflection has gone very much beyond 2 ins. Aluminum to withstand strains, and especially to have good elasticity, should be alloyed with a few per cent of impurities and cold-rolled, or otherwise worked cold. In this way it can be made to be nearly as strong and elastic as mild steel, section for section, and weight for weight will be much more rigid.

Aluminum and copper form two series of valuable alloys; the aluminum bronzes, ranging from 2 to 12 per cent aluminum with copper, and the copper-hardened aluminum series, with from 2 to perhaps 15 per cent of copper with the aluminum. The aluminum bronze series are already beginning to assume an important position in the arts, and I believe will very largely replace brass and other

bronzes, and for some purposes take the place of steel. By adding 8 to 12 per cent of aluminum to copper, we obtain one of the densest, finest grained, and strongest metals known,—a metal having a remarkably good ductility as compared with its tensile strength. A 10 per cent bronze can readily and uniformly be made in forged bars, with 100,000 lbs. per square inch tensile strength, with 60,000 lbs. elastic limit per square inch, and with at least 10 per cent elongation in 8 ins.; and aluminum bronzes can be made to meet a specification of even 130,000 lbs. per square inch and 5 per cent elongation in 8 ins. Such bronzes have a specific gravity of about 7.50, and are of a light yellow color. The 5 to 7 per cent aluminum bronzes have from 8.30 to 8 specific gravity, and a handsome yellow color. They readily give 70,000 to 80,000 lbs. per square inch tensile strength, with over 30 per cent elongation in 8 ins., and with an elastic limit of over 40,000 lbs. per square inch. It will probably be alloys of the latter character that will be most used, especially for marine work. The fact that 5 to 7 per cent bronzes can be rolled or hammered at a red heat, proper precautions which can readily be secured being taken, will add greatly to their use. Metal of this character can be worked in almost every way that steel can, having for its advantage greater combined strength and ductility, and much greater power to withstand corrosion. By far the best results have been obtained by using the purest aluminum and purest copper. The presence of silicon in aluminum alloys makes a harder bronze, but one of much less comparative ductility and malleability. The presence of iron weakens and very seriously interferes with the value of bronze. Tin also is disadvantageous. The presence of zinc in the aluminum bronze is not so deleterious; in fact, it makes the best aluminum bronzes much better than those having tin in them.

The Cowles and Heroult people, who by their methods manufacture aluminum bronze by direct reduction, have claimed that the bronze directly reduced was more homogeneous and better than that made by melting together copper and pure aluminum. Careful experiments made in this matter, however, have failed to show this claim to be true. From my experience, I entirely agree with Prof. Richards, who, in his excellent work, says: "Two specimens containing nothing but aluminum and copper in like proportions will be identical, no matter how they are produced." As it is far easier, and at present

cheaper, to produce a bronze with less iron and silicon by using pure aluminum of less than 2 per cent of these impurities, which with pure copper will give less than $\frac{1}{2}$ of 1 per cent impurity in the bronze, the advantage is certainly on the side of the use of pure aluminum, melting it with pure copper, so far as quality is concerned.

The aluminum in bronzes lowers the melting point of the copper at least 100° or 200°. The melting point of 10 per cent aluminum bronze is somewhere in the neighborhood of 1700° F.

Aluminum bronze is among the hardest of the bronzes, and hardens upon cold-working considerably. This hardness, however, can readily be lowered by annealing at a red heat and plunging into cold water. Aluminum bronze can readily be worked in a lathe, and the chips cut clean, smooth, and long, and do not clog the tool. Aluminum bronze is a remarkably rigid metal under transverse strain, being much more rigid than ordinary brass, or even gun bronze. Under compression its strength, although rather low in elastic limit compared to its ultimate compressive strength, is still much higher than that of any of the other bronzes, and there is a long period of gradual compression before finally giving way, making it peculiarly a safe metal under compression.

Aluminum bronze has excellent anti-friction qualities, owing to its fine grain texture and peculiar smooth and unctious though hard surface, which resists abrasion remarkably. Attention has already been called to the anti-corrosive qualities of aluminum bronze; and as its electrical conductivity is better than that of brass, it is peculiarly well adapted for commutator bars in dynamos. It can be brazed and soldered nearly as well as brass.

Sound, clean castings of aluminum bronze can be safely and regularly made, either in sand molds or against chills, if the proper precautions are taken to avoid: first, oxidation; second, contamination from scum or a cinder composed of oxide of aluminum with a little copper in it; third, depressions, cracks, or strains due to shrinkage; fourth, the shutting in of gas into the castings. The first trouble, oxidation, is due to heating the metal too hot in the plumbago crucible. The copper should not be heated much above its melting point before the aluminum is added, which at first absorbs a great deal of heat and rapidly thickens the metal, the aluminum being rapidly immersed in the copper to prevent its oxidation. Great care should

then be taken in again bringing the metal up to the liquid condition, and the metal should be frequently stirred; for it suddenly heats up by the reaction of the alloying of the two metals, and, unless precautions are taken, will soon bring the temperature up to a white heat, where oxidation will seriously injure the bronze. The metal should have a cover of powdered charcoal to prevent oxidation, but with no other flux over its surface.

The second trouble, contamination from the scum, can be avoided by pouring from the melting furnace or pot into a hot ladle or pouring basin large enough to hold all the metal necessary to fill the mold and to allow the metal to pour out from the bottom of such a receptacle after giving sufficient time to allow the scum to come to the surface. A skim-gate should also be provided for each mold.

The third difficulty is caused by a peculiar red-shortness just after solidification, and also a contraction at solidification which causes the metal to either tear apart or yield and cause depressions in the casting at more favorable spots, if any great resistance is experienced by the metal in contraction. This difficulty is overcome by giving bountiful allowance for the contraction, which can be done in several ways, each best adapted for varying conditions. The cores should be made of a yielding character, using resin or other suitable substance with coarse sand, that will yield to slight pressure. Unyielding iron core rods should be dispensed with as far as possible. "Green" sand cores will give good results in some cases. Other expedients to gain the same ends will be easily suggested by skilled molders.

The troubles due to shrinkage are avoided by having the "risers" or "feeding heads," with flaring openings, large in section, often larger than the castings they are intended to feed, and if necessary refilling the feeding heads, in some cases several times over. In this way the casting will solidify first, drawing metal to supply its shrinkage from the still fluid riser having a level higher than the casting itself, so that the metal will flow down into it. The gates to the mold should be sufficient in number and so arranged that they can be filled with the metal as cold as it will pour and give full castings. The considerable amount of scrap occasioned by the large sectioned risers can be remelted without loss of aluminum, and, indeed, is improved in quality by the process of remelting.

To prevent the shutting in of gas into the castings, dry sand

should be used, and the molds should be well vented by the ordinary precautions taken by founders for this purpose. Although it requires skill and experience to successfully carry out the conditions outlined above, sound, clean castings, even of the most difficult sections of aluminum bronze, can be made regularly, and with no more wasters than with ordinary brass, and without the difficulty of a copious liberation of gas at the moment of solidification, as is the case with steel. In fact, aluminum bronze, with its low pouring temperature, is especially applicable for massive and heavy castings.

The alloys of aluminum with copper in proportion of from 2 to 15 per cent have already been incidentally referred to. Copper, I believe, is one of the best hardeners of aluminum. The maximum proportion that can be added before the metal becomes too brittle to work depends largely upon the purity of the aluminum. If it contains several per cent of silicon it becomes very brittle with 5 per cent of copper; but with pure aluminum it is still forgeable, with difficulty, with 15 per cent of copper. Even very small percentages of copper added to pure aluminum decrease the blue color of the metal and give a more pleasing yellow-white color to it.

Proportions of a few per cent of copper added to pure aluminum decrease the shrinkage of the metal and give alloys that are especially adapted for art castings. The remainder of the range, from 15 per cent copper up to over 85 per cent, give crystalline and brittle alloys of no use in the arts, and of a grayish-white color, up to 80 per cent, where the distinctly yellow color of the copper begins to show itself.

There is said to be an alloy of 50 per cent copper and 50 per cent aluminum which is malleable. I have, however, been unable to discover any such alloy in experiments which I have made in this direction, all of the alloys being very crystalline and brittle.

Aluminum combines with iron in all proportions. None of the alloys, however, have proved of value, except those of small percentages of aluminum with steel, cast iron, and wrought iron. So far as experiments have yet gone, other elements can be better employed to harden aluminum than iron, and its presence is regarded as entirely a deleterious impurity, to be avoided if possible.

The addition of from $\frac{1}{2}$ lb. to 2 lbs. of aluminum to a ton of steel gives the advantage of quieting the metal in the mold and producing

ingots with much sounder tops, so that the scrap due to crop ends is materially lessened, a saving which much more than pays for the cost of the aluminum added. The amount to be added varies with the character and condition of the steel. With well-melted steel, low in carbon, the proportion of from $\frac{1}{8}$ to $\frac{1}{2}$ lb. to the ton seems to give the best results; any larger proportion making the metal pipe and causing excess of crop-end scrap. If the steel be "wild" in the ladle, full of occluded gases, too hot, or oxidized, a larger proportion of aluminum can be advantageously added. Mr. R. A. Hadfield says, I think correctly, that the influence of aluminum appears to be like that of silicon, though acting more powerfully. The same writer, together with Prof. H. M. Howe and Mr. Osmund, claims that an addition of aluminum does not lower the melting point of steel. In this my own experience agrees; nor do I believe that aluminum increases to any great extent the fluidity of the steel. So far as my experience goes, steel, with an addition of $\frac{1}{10}$ per cent of aluminum, seems to solidify in the molds fully as quickly as steel without the addition of the aluminum. Aluminum seems to take the oxygen out of steel very much in the same way that manganese does, but I am not aware of any advantages gained by using the more expensive aluminum for this purpose.

The addition of aluminum in quantities of from 2 to 3 lbs. per ton are of advantage where the steel is to be cast in heavy ingots which will receive only scant work. Here it seems to increase the ductility as measured by the elongation and reduction of area of tensile test specimens, without materially altering the ultimate strength.

The question as to whether additions of aluminum prevent segregation of impurities in large castings of steel is still an unsettled one; but I may say that it is now being carefully investigated.

In steel castings the benefit from the use of a small percentage of aluminum, ordinarily in the proportion of from 2 to 3 lbs. per ton, has become widely recognized, and it is being generally used.

The additions of aluminum are almost always made by throwing the metal, in pieces weighing a few ounces each, into the ladle, as the steel is pouring into it. In cast-iron, from 2 to 5 lbs. of aluminum per ton is put into the metal as it is being poured from the cupola or melting furnace. To soft gray No. 1 foundry iron it is doubtful if the metal does much good, except, perhaps, in the way of keeping

the metal melted for a longer time ; but where difficult castings are to be made where much loss is occasioned by defective castings, or where the iron will not flow well, or give sound and strong castings, the aluminum certainly in many cases allows of better work being done and stronger and sounder castings being made, having a closer grain, and hence much easier tooled. The tendency of aluminum is to change combined carbon to graphitic, and it certainly lessens the tendency of the metal to chill. Aluminum in proportions of 2 per cent and over materially decreases the shrinkage of cast iron.

The effect of aluminum in wrought iron is not very marked in the ordinary puddling process. It seems to add somewhat to the strength of the iron, but the amount is not of sufficient value to induce the general use of aluminum for this purpose.

The peculiar property of aluminum in reducing the long range of temperature between that at which wrought iron first softens and that at which it first breaks down and becomes fluid is taken advantage of in the well-known Mitis process. It is for this that aluminum is most used in wrought iron at present.

With the exception of lead, antimony, and mercury, aluminum unites readily with all metals ; and many useful alloys of aluminum with other metals have been discovered within the last few years. I venture to prophesy the finding of many more in the near future, as more systematic attempts are made to study the use of aluminum with other metals and metalloids. Of many of these useful improvements that are now subjects of letters patents, for obvious reasons, I will say nothing. The useful alloys of aluminum so far discovered are all in two groups, the one of aluminum with not over 15 per cent of other metals, the other of metals containing not over 15 per cent of aluminum ; in the one case, the other metals imparting hardness and other useful qualities to the aluminum, and in the other the aluminum giving useful qualities to the other metals.

The alloy of a few per cent of silver to aluminum, to harden, whiten, and strengthen the metal, gives a metal especially adaptable for many fine instruments, tools, and electrical apparatus, where the work upon the tool and its conveniences are of more consequence than the increased price due to the addition of the silver. The silver lowers the melting point of aluminum, and gives a metal susceptible of taking a fine polish and making fine castings.

More or less useful alloys have been made of aluminum with zinc, bismuth, nickel, cadmium, magnesium, titanium, chromium, manganese, and tin,—these alloys all being harder than pure aluminum; but it is by combinations of these metals, with additions perhaps of copper, lead, and antimony, that alloys of most useful value have so far been discovered. Some are with additions of only 1 to 2 per cent of aluminum.

The addition of from 5 to 15 per cent aluminum to type metal composed of 20 per cent antimony and 80 per cent lead makes a metal giving sharper castings and a much more durable type.

To ordinary brass, the addition of aluminum gives superior strength and better anti-corrosive qualities. Some very marked and valuable qualities have been discovered in the use of aluminum with zinc for various purposes.

The modifications of pewter, Britannia, white metal, Delta metal, and the like, with additions of aluminum, have shown very useful qualities, and will add very considerably to the demand for aluminum in the near future.

Evidently, contrary to the understanding of the case by many people who have written us with brilliant claims of rich mines, aluminum has never been found in nature in the metallic state; and yet the general statement made by Prof. Richards is true, that "there is no other metal on the earth so widely scattered, and that occurs in such abundance." This statement, however, has been interpreted by the public to the effect that therefore all these varied minerals containing aluminum are equally applicable as ores from which to extract the metal; especially have they considered that clays, silicates of aluminum, are the specially chosen ores for the production of aluminum. A consideration of the comparative constituents of clay with those of the minerals given below shows the disadvantage of the richest of clays, as aluminum ores, as compared with the richer and purer oxides, fluorides, and sulphates, which minerals are now used as ores of aluminum.

Bauxite ($\text{Al}_2\text{H}_5\text{O}_6$), soft and granular; with 50 to 70 per cent oxide of aluminum and with only a few per cent of accidental impurities besides the water of hydration.

Corundum (Al_2O_3), very hard and crystalline, specific gravity 3.909.
— With 93 per cent alumina and ordinarily very free from impurities, but

so hard and crystalline, and withal so valuable for other purposes, as not to be at present used as an aluminum ore.

Diaspore ($\text{Al}_2\text{O}_3\text{H}_2\text{O}$), hard and crystalline; specific gravity, 3.4.—With 65 to 85 per cent alumina and ordinarily very pure.

Cryolite ($\text{Al}_2\text{F}_6\cdot 6\text{NaF}$), specific gravity, 2.9.—With 40 per cent aluminum fluoride and 60 per cent sodium fluoride.

Aluminite ($\text{Al}_2\text{SO}_4\cdot 9\text{H}_2\text{O}$), specific gravity, 1.66.—Containing some 30 per cent of alumina in a condition to be cheaply purified by solution, filtration, and roasting.

Gibbsite ($\text{Al}_2\text{O}_3\cdot 3\text{H}_2\text{O}$), stalactitic; specific gravity, 2.4.—Containing about 65 per cent alumina.

In comparison with these, the clays vary from tri-basic silicates of alumina to pentacid silicates, minerals with at best 65 per cent alumina and 35 per cent silica; while the more common clays contain from 50 to 70 per cent silica and only from 50 to 35 per cent alumina. Pure kaolin contains 39 per cent alumina, carrying about 20 per cent aluminum, with 40 per cent silica, and 14 per cent water. It has a formula of $\text{Al}_2\text{Si}_2\text{O}_7\cdot 2\text{H}_2\text{O}$. Now silica is much easier reduced than alumina, and by all the methods of reduction this large percentage of silica must be separated from the alumina before the reduction is commenced, else a large percentage of energy used in reduction will be expended in reducing a troublesome impurity, instead of in reducing the alumina to aluminum. The true value of clay as an ore of the metal is evident, therefore, in comparison with the richer and purer ores that have only accidental amounts of iron and silicon, up to perhaps 10 per cent, to be removed before being submitted to the reducing operation.

There seems to be one fact favorably prominent, however, in the prospect of fat clays like the kaolins being used as aluminum ores,—that is, that concentrated cold sulphuric acid dissolves the alumina out of most clays, leaving the silica insoluble. Although this fact has not yet, to my knowledge, been made use of on a commercial scale, still in the future, when there is a large demand, this method may make clays available as ores of aluminum.

Bauxite is the mineral most used at present for the manufacture of alumina, and it probably will continue to be the most economical ore, for the reason that it is soft, easily ground, and easily decomposed to separate the impurities of silica and iron. The mineral occurs in great abundance in the south, in Tennessee, Virginia, North and South

Carolina, Georgia, Alabama, and also Arkansas. Very pure bauxites can be laid down in quantities in Pittsburgh at a cost of between \$9 and \$10 per ton, and with only the cost of mining and transportation can be put on cars nearest the mines in many cases at a cost of less than \$2.50 per ton.

The general method of purification of the ore is to calcine the bauxite with just sufficient sodium carbonate to form sodium aluminate ($\text{Al}_2\text{O}_3 \cdot 3\text{Na}_2\text{O}$). The temperature must be kept below the melting point (the aluminate being formed at a temperature lower than the melting point of the mixture), else silicate of aluminum is formed. The mass is well stirred to insure the complete displacing of all the carbonic acid and the combination of the sodium carbonate with the alumina. A ready test of the completion of the reaction is that portions taken from the mass no longer effervesce and evolve carbonic acid upon treatment with acid. The incinerated mass is taken out of the furnace, ground and lixiviated with hot water, which takes the sodium aluminate into solution, leaving the silica and iron insoluble. The clear supernatant sodium aluminate solution is siphoned off, and the alumina is precipitated with carbonic acid gas. This forms sodium carbonate, which remains in solution, while the alumina settles out to the bottom of the tank. This is afterwards washed with hot water and dried.

The same general method of treatment is applicable to the aluminum oxide minerals for their preparation; the difficulties to overcome being in grinding the minerals, because of their hardness and the formation of the sodium aluminate at a low enough heat to prevent the sodium silicate forming. It may be that these minerals had best be taken into solution as sulphates, and thereafter treated as the native sulphates by a red heat to drive off the sulphuric acid, leaving pure alumina as a residue. With proper apparatus to condense and save the sulphuric acid, such processes may not be excessively expensive. However, neither this method of manufacture of the sulphates from clays or from native oxides, nor the method of manufacture of alumina from the sulphate by roasting, have so far found favor commercially in comparison with the soda carbonate fusion method for the preparation of the oxide. The sulphate of aluminum melted with sulphur gives off sulphuric acid gas and transforms the alumina into sulphide. This reaction has been made available in one of the methods of manu-

facture of aluminum from sulphide by the aid of electricity; the sulphide being afterwards decomposed by electrolysis.

Aluminate of soda is made from cryolite by the incineration of finely ground cryolite with an intimate mixture of chalk or finely ground carbonate of lime, with enough ground coke to keep the mixture porous. Soluble aluminate of soda is formed; insoluble fluoride of lime remains as a waste product, together with carbonic acid which is evolved. The precipitation of the alumina from the aluminate of soda is carried on by the same method as previously described.

Aluminum sulphide, a yellow, infusible salt, containing 36 per cent aluminum, is produced from alumina by the reaction of carbon bi-sulphide at a high heat in the presence of carbon. It is also prepared, as explained, by the fusion of aluminum sulphate in the presence of sulphur. It is a rather unstable compound, being decomposed by standing in moist air into alumina, with the evolution of sulphureted hydrogen.

The chloride of aluminum was for a long time the chief salt from which the metal was produced, for the reason that it had been found that metallic sodium reduced the metal from this salt the easiest. For a long time the only practical way of cheapening the manufacture of aluminum by this method was to cheapen the manufacture of sodium and reduce the expense and improve the quality of the aluminum chloride. This proved a difficult task.

The salt varies from pure white, when pure, through the yellows to a brick-red when largely contaminated with ferric oxide. It is produced by the action of chlorine gas upon an incinerated mixture of alumina with tar or some oil that will, on burning out during the incineration, leave its coke in intimate mixture with the alumina.

The double chloride of aluminum with sodium is produced if a supply of salt is added to the mixture and it is treated with chlorine gas. The expense and difficulties connected with the manufacture have proven very large, and the chlorine produced has to be very carefully made to keep it free from iron. The difficulties connected with the generation and use of chlorine gas on a commercial scale are found to be very great and the deterioration of the apparatus to be very serious.

The native fluoride of aluminum and sodium, the mineral cryolite, has been used in several processes as the ore for the production of

aluminum. It, however, contains too much silicon and oxide of iron to make pure metal; for, as before said, in all the methods so far devised, or which seem likely to be devised in future, the agents that serve to reduce the aluminum to a metallic state will surely reduce all the silicon and iron from their oxides that may be present at the same time or rather previous to the reduction of the aluminum. Pure aluminum fluoride (Al_2F_6) is produced by the action of sulphate of aluminum on cryolite, sulphate of soda being the by-product, according to M. Grabau. Aluminum fluoride can also be produced by the action of hydrofluoric acid of alumina. It is not such an expensive or difficult salt to prepare as the chloride, and is the compound from which aluminum is produced in many of the later and more successful processes. Metallic sodium reduces the fluoride of aluminum with the same facility with which it acts upon the chlorine compounds.

Aluminum cannot be reduced from its oxide by the aid of carbon as a reducing agent, because the temperature to which the intimate mixture of the solid carbon and the alumina has to be raised can only be attained by the highest heat of an open-hearth furnace or in the electric furnace,—a temperature at which the aluminum reduced cannot itself be accumulated into a molten liquid mass, and can only be retained by cloaking it with a more stable metal like iron or copper. It is for this reason that the Cowles Electric Smelting & Aluminum Company are not able in their electric furnace to manufacture commercially pure aluminum, nor the Heroult people to manufacture the metal from their process of reduction, where they electrolyze pure molten alumina, which requires a high electrically produced heat to melt the oxide. None of the other salts are susceptible of being reduced by carbon at much lower temperature than the oxide, so far as yet discovered.

Debarred from using carbon as the reducing agent under the ordinary conditions which make it the practicable and economical reagent in most metallurgical operations, the advantages of other stronger reducing agents have been carefully tried. So far only one has proven commercially available, although there are many other agents capable of reducing the metal from its oxide. Metallic sodium reduces the metal from its chloride or from its fluoride salts with ease. Methods based upon the use of sodium as the reducing agent have until lately given not only the purest but the cheapest aluminum.

These methods, however, of late, have been succeeded by the cheaper and more direct processes of electrolysis of some of the aluminum salts or of the pure oxide.

So far as history informs us, Wöhler in 1827 first reduced metallic aluminum by the aid of metallic potassium as the reducing agent from aluminum chloride. The metal was a dry powder in a finely comminuted state; it was very impure, and was only a metallic curiosity. Deville, twenty-seven years later, in 1854, was the first to produce the metal in any quantity, or with any degree of purity.

It is curious to note that the first pure aluminum made was by electrolysis; both Bunsen and Deville reduced the double chloride of aluminum and sodium by electricity generated by galvanic batteries. But as at that time the dynamo was still a machine of the future, electrolysis was soon abandoned for the sodium process by the successful concerns in the manufacture of the metal, although continued experimental efforts were made with electricity from that time to this. The first aluminum made in 1855 was valued at \$90 per lb. In 1857, with the development of the sodium method of reduction, the price was lowered to from \$28 to \$32 per lb. In 1860 the price was again lowered to about \$17 per lb., and from 1862 to 1887 the price ranged from \$12 per lb. upward, according to purity. In 1887 the price was reduced to one pound sterling per pound avoirdupois; and it was at this price that the first metal made was sold by the new concerns built during that year. In 1889 the Pittsburgh Reduction Company reduced the price to \$2 per lb. As the English works of the Pittsburgh Reduction Company commenced in 1890 to sell the metal in England at five shillings (\$1.21) per pound, I presume that future writers will record a further drop in the price of the metal in 1891.

About 1857 the famous works at Salindres were established, which were under the proprietorship of Pechiney & Company, for many years, and, until within the past three years, enjoyed not only the reputation of making the best but the largest amount of aluminum produced in the world. The care and skill shown, and the ingenious devices and precautions taken by the firm to prevent impurities in the metal by the cumbersome and expensive sodium process in which there were so many opportunities for the addition of impurities, were worthy of the highest praise. In 1860 Sir I. Lowthian Bell, with a brother, started works at Newcastle-on-Tyne, which were abandoned

in 1874. They manufactured by the sodium process. From 1874 until 1882 the French company at Salindres was the only concern making pure aluminum.

In 1882 Webster organized the "Aluminum Crown Metal Company," at Hollywood, near Birmingham, England, and by cheapening the production of aluminum chloride soon developed a successful concern. This was further strengthened by the improvement of Mr. H. Y. Castner, an American chemist, who, in 1886, patented improvements for producing a more intimate mixture of the carbon with the caustic soda in a state of fusion by means of a carbide of iron, in this way cheapening by more than one half the cost of manufacture of metallic sodium, which had been \$1 per lb. This concern was organized under the name of the Aluminum Company, Limited, and put up a large and expensive plant at Oldbury, near Birmingham, England. These works were started at the end of June, 1888, and they have been manufacturing up to within the past six or nine months. In common with the other manufacturers by the sodium process, they have been working at great disadvantage since the advent of the more successful electrolytic processes.

Early in 1888 the Alliance Aluminum Company started works at Wallsend-on-Tyne, England, using a process which was an innovation upon the Deville sodium process, by using the fluoride or the double fluoride of aluminum and sodium cryolite as the compound to be reduced instead of the chloride or the double chloride of the metal. Prof. Nette, the managing director of the concern, also had a process for producing metallic sodium cheaply by allowing fused caustic soda to trickle over incandescent charcoal in a vertical retort. Some very excellent aluminum was produced at these works; they became involved in a law suit, however, with the Aluminum Company, Limited, and the newer processes coming up caused them also to close their works, which have now been shut down for over a year.

In spite of the broad claims of the Cowles Brothers to the use of electricity for metallurgical purposes, the first actual reduction of aluminum in a metallic state on a practical scale by Deville in 1854 was, as we have seen, by the aid of electricity, electrically decomposing the chloride. Even then the idea was old, for Sir Humphry Davy in 1810 publicly described the successful experiment made in 1807, in which he connected the negative pole of a battery of 1000 double

plates with an iron wire which he heated to a white heat and then fused in contact with moistened alumina, the operation being performed in an atmosphere of hydrogen. The iron upon analysis was found to be alloyed with aluminum.

Bunsen in Germany and Deville in France, in 1854, each electrolyzed the double chloride of aluminum and sodium. Le Chatelier obtained English patent No. 1214, in 1861, and Monckton, in 1862, English patent No. 264 for the reduction of aluminum by aid of electricity. In fact, Richards says that the Monckton patent "proposes to pass an electric current through a reduction chamber, and in this way to raise the temperature to such a point that alumina will be reduced by the carbon present," showing that not only was the use of electricity for reducing aluminum old, but that the idea of the electric furnace was twenty years old at the date of the first of the Cowles patents in 1885.

Richards, in his work on aluminum, mentions and gives the published authority in each case of the processes for reducing aluminum with the aid of electricity; of Gaudin, 1869; Kagensbusch, 1872; Berthaut, 1879; and Gratzel, 1883.

The newer pure aluminum processes using electricity of Hall, Heroult, and the Bernard Brothers, with the help of Minet, together with the alloy processes of the Cowles Brothers and of Heroult, are the only ones that are now being worked upon a commercial scale, so far as I know, though perhaps the meritorious inventions of Mr. Graubau may have been reduced to practical working of late. Of this I am uncertain, or of what is being done by Herr Saarburger at Hemelingen, near Bremen. I only know that we no longer hear of the Aluminum & Magnesium Fabrik Company's aluminum in the competition of the markets, or of any metal made by the sodium process.

Besides these, there have been a host of other electrical attempts and experiments for the manufacture during the past two years, since the success of some of the other companies using electricity became known.

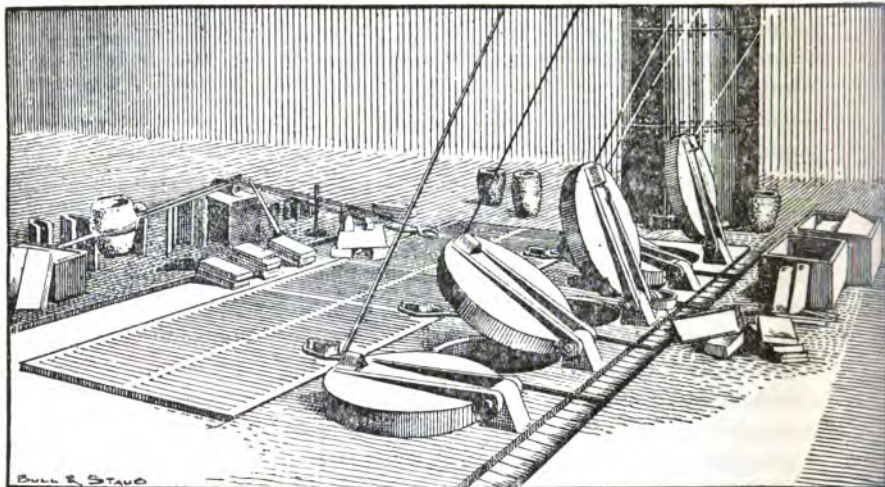
The Hall process of manufacturing aluminum is owned by the Pittsburgh Reduction Company, who have, in addition to 390 electrical horse-power at work in Pittsburgh, another plant of about equal size at Patricroft, Lancashire, England, the Pittsburgh works commencing to manufacture in November, 1888, and the English works in July, 1890.

The Hall process consists in electrolyzing alumina dissolved in a fused mixture of fluorides of aluminum and sodium or of fluorides of aluminum and potassium, or, in fact, Mr. Hall has covered in his letters patent No. 400,667 a fused bath in which the alumina is dissolved in the fluoride of aluminum, together with the fluoride of *any* metal more electropositive than aluminum.

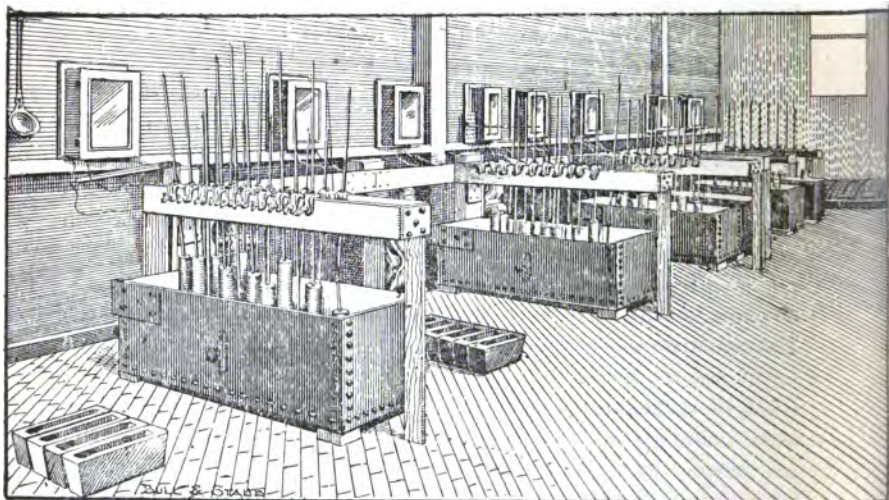
As the Pittsburgh Reduction Company uses the process, it places the mixture of fluoride salts in a row of carbon-lined iron tanks placed in series. The pots, together with their carbon linings and the reduced metal in bottom of the pots, become the negative electrodes or cathodes. The positive electrodes or anodes are a series of 3-inch diameter carbon cylinders, attached by $\frac{3}{8}$ -inch copper rods to the copper conductors by the aid of suitable binding screw clamps. The current of 5000 amperes and fifty volts in one series, and of 2000 amperes and 20 volts in the other series, is turned on, and the mixture is melted by the heat caused by the resistance offered to the current by the fluoride mixture. In less than two hours' time the mixture becomes fluid, and alumina is added. The electrolyte then becomes a much better conductor, "the resistance of the pot" goes down to a normal one of about 8 volts, and the operation of electrolysis commences. The alumina in solution, or, as some claim, the fluoride of aluminum, is decomposed; the metal, being heavier than the electrolyte, sinks to the bottom of the pot, and the oxygen goes to the positive carbon electrode, uniting with a portion of the carbon and escaping as carbonic acid gas; or, as is maintained by some, the aluminum of the fluoride of aluminum is deposited, and the fluorine attacks the dissolved oxide, reforming fluoride of aluminum, and thus maintaining the integrity of the original electrolyte bath, the oxygen going off, as in the other case, at the positive electrode.

While the actual fact as to which reaction takes place is not essential to the validity of the Hall patents, and the Pittsburgh Reduction Company makes no claims regarding the matter, it is our belief that the compound electrolyzed is alumina. I may say, in this connection, that this is the view of Prof. J. W. Langley, Prof. Richards, and of all the other metallurgists who have had experience with and have given the actual metallurgical operations careful study.

Among the reasons for our belief are the heat of formation of alumina, 391,600 calories; the fact that it requires only 2.8 volts to



MELTING HOLES — PITTSBURGH REDUCTION COMPANY'S PROCESS.



REDUCING POTS — PITTSBURGH REDUCTION COMPANY'S PROCESS.

decompose it; the probable fact that the heat of formation of the aluminum of fluoride is very considerably greater; the fact already established that it requires a very much higher voltage than 2.8 to decompose the electrolyte that we use; and the fact, already mentioned, that when the bath gets out of alumina the resistance rises considerably (ordinarily about four volts), and that the heat rises rapidly in the pot until the electrolyte itself begins to decompose, and stifling white fumes of hydrofluoric acid begin to be given off.

Again, fluorine displaces oxygen in alumina; hence we reason that aluminum fluoride is a stronger compound than alumina. Sodium reduces aluminum fluoride,—the basis of the Grabau process. Ergo, sodium fluoride is a stronger compound than aluminum fluoride. Hence, in a bath containing sodium fluoride, aluminum fluoride and alumina, in nearly equal proportions, the order in which they will be decomposed by an electric current of graduated intensity, or in conditions similar to the Hall bath, will be alumina, aluminum fluoride, and sodium fluoride. Again, the electro-motive force required to decompose compounds is in proportion to the heat evolved in the formation of electro-chemical equivalent weights of the compounds, and sodium fluoride is thermally much greater than $\frac{1}{3}$ of a molecule of aluminum fluoride, or of a molecule of alumina.

According to my understanding of the case, the difference between the Hall process and the Heroult alloy process is this: Hall electrolyzes alumina made fluid at a lower temperature by dissolving it mechanically in a fused fluoride solvent, lighter than aluminum, which will not corrode the metal, and above all will not be itself decomposed by the electric current (or at least will not stay decomposed), and which is a sufficiently good conductor of electricity to allow the temperature of the molten bath not to reach much above the melting point of the metal. In the Heroult process they electrolyze alumina made fluid by the intense heat of the electric arc, at a temperature at which the metal has to be protected by being alloyed with copper or iron in order to retain it.

In the practice of the Hall process the heat is retained in the molten bath by a covering of finely powdered carbon on the surface of the molten mixture. On top of this carbon raft the powdered alumina is placed, and when the voltmeter attached to each pot shows a rising resistance, the pot-tender stirs in more heated ore from the

surface of the pot. The carbon soon comes to the surface, when a fresh supply of ore is placed on it. The feeding is thus easily made continuous, and as the electrolyte remains constant it only requires tapping the metal off,—or, as is rather crudely but very satisfactorily done, dipping the metal out in cast-iron ladles, and skimming the electrolyte back into the pots with the carbon rods,—to make the entire operation continuous. The pots are run for months at a time. The following are the chief advantages of the continuity of the process:—

1. *Purity of the Metal.*—After the first run of metal is cast, carrying with it all the iron and silica, or rather the reducible impurities of the electrolyte, the only other sources of impurity are in the pure alumina added and in the ash of the positive carbon electrodes, which are worn away in the proportion of a little less than weight of carbon to the weight of metal produced.

2. *Saving of Material.*—The loss of metal and ore in a finely divided state in the bath, which occurs when a shut-down is required, is avoided. To be sure, this loss can be largely avoided by re-melting again; but in melting down the metal in a finely divided state it is found to be almost entirely re-dissolved. As continuously carried on, the loss of metal is practically nothing, every particle being reduced; undoubtedly it is often reduced more than once by being re-dissolved before settling through the bath to the metal below, when the ore gets out of the electrolyte and it becomes acid. At the same time, as there is no slag or other waste product, solid or liquid, evolved, and as the gases can carry off none of the aluminum, all of the aluminum in the ore added is finally brought out in ingot metal, a result that is seldom experienced in the reduction of metals from their ores.

3. *Economy*—The original heat of the electrolyte is constantly maintained, and the only supplies needed are the constant electric current, the alumina ore and fresh carbon electrodes to replace those worn out, with only occasional additions of fresh electrolyte to replace the small loss of that taken out with the ingot metal or that which has become decomposed by the workmen carelessly letting the pots get out of ore. This decomposition of the electrolyte means an infusible “cake,” as the workmen call it, settling to the bottom of the pot and filling it up. When the pots are not skilfully run, or more easily decomposing electrolyte mixtures are used, this accumulation shortens

the run of the pot, and also decreases the out-put. In the regular practice of the Pittsburgh Reduction Company there is practically no decomposition of the electrolyte, and a pound of aluminum is made with an expenditure of about 22 electrical horse-power per hour.

This electrical energy expended in heat is not very expensive. Supposing water power to be used at a cost of \$12 per horse-power per annum, allowing 25 per cent for loss in converting mechanical into electrical energy, and supposing 75 per cent of this energy to be converted into heat, Prof. Richards has calculated the heat generated by 1 horse-power during one year as 8,400,000 heat units.

The Hall process can be successfully carried on entirely independent of carbon, using a thick iron or copper tank, and either iron or copper electrodes. The deposition of the metal is nearly as large as with the use of carbon electrodes; but it is, of course, alloyed with copper or iron from the metal worn away from the positive electrode.

The Pittsburgh Reduction Company has made alloys of aluminum with iron and copper by this process similar in character to the alloys produced by the Cowles and Heroult alloy processes.

Almost at the same time that Hall invented his process for manufacture of aluminum, in the early part of 1886 (his first patent application dating July 9, 1886), M. Pierre Heroult commenced operations and afterwards took out English patent No. 7426 of 1887 for fluxing alumina with cryolite. The bath was put into a graphite crucible, which served as a negative electrode, and this was put inside a larger crucible, the space between the two being filled with graphite, and the carbon positive electrode being immersed in the fused bath. The ideas of M. Heroult and Mr. Hall at the start were very nearly identical. M. Heroult attempted to obtain an American patent, and was declared in interference with Hall; and, after the testimony as to dates of invention and of the application for patents, M. Heroult withdrew in favor of Mr. Hall. This process was practically abandoned for a while by M. Heroult in favor of his very successful alloy process of electrolyzing and reducing molten alumina; but since 1889, when a growing demand sprung up for pure aluminum, and the success of the Hall process became known, I understand that two concerns have begun working under the same principles,—the Aluminum Industrie Actien Gesellschaft, at Neuhausen, Switzerland, and a concern at Froges (Isère), in France, called the Société Électro-metallurgique de

France. I have seen some very pure and excellent metal from the Swiss concern.

The process commonly called "the Minet process," as developed and used at the works of the Bernard Brothers at Creil, Oise, France, consists in electrolyzing a mixture of sodium chloride with aluminum fluoride, or with the double fluoride of sodium and aluminum, their English patent dating July 18, 1887, No. 10,057. This company, I understand, have been doing successful work, and are now putting on the market aluminum of good quality. Thus it will be seen that there have developed apparently three separate electrolytic processes for the manufacture of pure aluminum at about the same time, all of which are working on about the same lines. These, together with the already much-written-about Cowles and Heroult processes for the manufacture of aluminum alloys, have for the past two years distanced all competitors manufacturing by the aid of metallic sodium, and are today in the possession of the aluminum market of the world.

And now I will close with a few remarks upon the prospects and possibilities of the future,—a subject in which, as President of the Pittsburgh Reduction Company, I am both financially and technically very much interested.

Theoretically, the cost price of the manufacture of aluminum by direct electrolysis has already been brought down very low as compared with the cost of the more complicated processes of a few years ago. The cost per pound is about as follows:—

2 lbs. of alumina (Al_2O_3 , contains 52.94% Al_2) at 3 cts. . .	\$0.06
1 lb. of carbon electrode at 2 cts.	.02
Chemicals, carbon dust and pots	.01
22 E. HP. exerted one hour, water power being used . .	.05
Labor and superintendence	.03
General expense, interest and repairs	.03
Total	\$0.20

I would say here that while the actual cost of the metal produced by the Pittsburgh Reduction Company, or any other of the concerns mentioned as actually putting aluminum in limited quantities on the markets today, are nothing like these figures as a total, at the same time, as the most economical methods are used, figures approaching these will undoubtedly be attained; and, moreover, improvements in

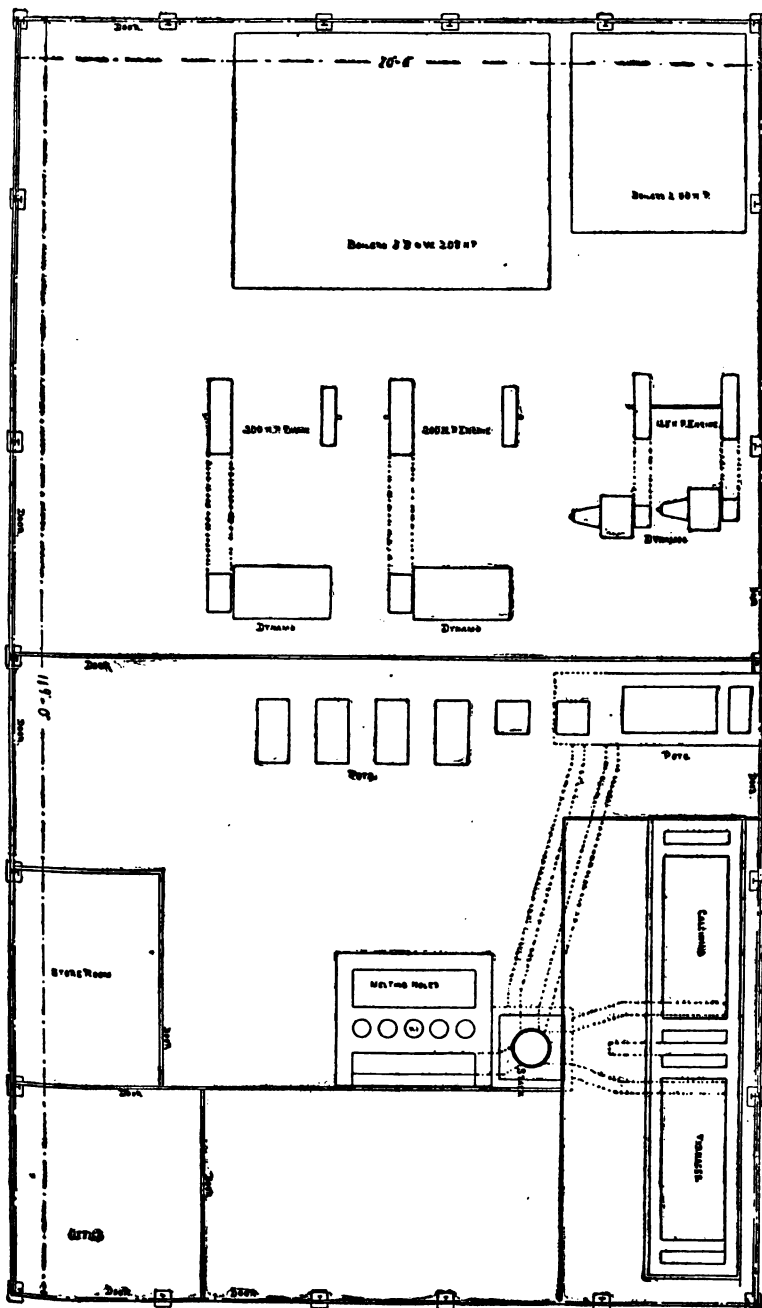
new processes will in many cases probably be equally applicable in reducing costs by the present electrolytic methods. As stated before in this paper, no process can be devised that will give less loss of ore than that of the Hall process, where it is practically nil, nor is it probable that any other method can be devised that is able to give purer metal than that made by the Hall process. Analyzing the items of cost given above, the ore will probably be the greatest item of expense in any successful process, and surely the oxide, alumina, is not only the richest and most easily prepared pure ore, but will prove one of the cheapest, if not the cheapest, of compounds from which to extract the metal. Quite surely no difference here in the art will make an insurmountable barrier of cost for the electrolytic processes now in use to compete against. The expenditure for other reagents than the ore, for carbon, and for chemicals, is now less than 5 cts. per lb. with the Pittsburgh Reduction Company, and in the estimate can fairly be reduced to 3 cts. per lb. for a large plant, with most favorable arrangements made for its supplies. In the item of electrical power there certainly may be room for a large curtailment of cost; but, even should this expenditure of electrical power be lessened one half, or entirely done away with, heat alone being substituted as the energy for reduction of the ore, it will be difficult to conceive of a method that would not require a cost of at least one cent for this heat, which would be a saving perhaps of 4 cts. per lb. upon this item of electrical power. However, I feel confident that, should such processes be devised, the increased expenditure for chemicals and other reagents besides the amount quoted as necessary for the Hall electrolytic process will nearly, if not quite, counter-balance the saving in electrical energy expended in the Hall process.

In the items of labor, superintendence and general expense, interest and repairs, there may be material saving made by a process yielding metal more rapidly than by the comparatively slow electrolytic process. But the plant required by the Hall process is very simple,—especially if located upon water power,—and the repairs are very small in proportion to the out-put. It will be doubtful, therefore, if a saving of more than 3 cts. per lb. can be made, or one half of the total estimated as necessary for the manufacture of aluminum by the Hall process. Thus the total saving probable, or, I think I am almost justified in saying, even in these days of wonderful inventions, possible,

is only about 7 cts. per lb. over the cost of the Hall process. A greater saving than this may perhaps be made if some bright artist shall be able with Aladdin's lamp to rub the clay bank with his magic wand and extract "the silver from the clay" by his incantations; or, perhaps, more soberly, some one may find a method of reducing aluminum from some of its compounds as a by-product, the expense of which shall entirely or mainly be borne by the other valuable products made.

In this connection an ingenious method has been devised to electrolyze the sulphide of aluminum, or the double sulphide of aluminum and sodium, in a tank, closed and suitably insulated, and connected with a powerful electric current. The tank is filled with charcoal, covered with alumina, or, in case the double sulphide is to be made, with a mixture of alumina and some sodium salt. The tank is heated to incandescence by the electric current, and fumes of sulphur are forced into the tank. An atmosphere of bi-sulphide of carbon is produced; the excess is carried away by a condensing pipe, and is calculated to yield revenue enough to pay for the entire operation, which consists further in reducing the sulphide of aluminum produced by a portion of the bi-sulphide of carbon acting upon the aluminum in the presence of the heated carbon. The sulphide of aluminum is electrolyzed in the lower part of the tank, the molten metal going to the bottom, where it is afterward tapped out. The evolved sulphur again attacks the hot coal and produces bi-sulphide of carbon. This process looks very pretty on paper, but, unfortunately, it has not thus far proved financially successful.

The only method which seems at all likely to supersede the electrolysis of alumina as the most economical method of manufacture of aluminum is some variation in the condition of reduction (such as performing under pressure or the like). The oxide, or an equivalent aluminum compound, would have to be cheaply prepared by the aid of carbon at a much lower temperature than is now possible by the means already tried. If such a feat could be accomplished, the changed conditions under which the carbon was to work not being too expensive to attain, and the reduction being accomplished rapidly enough to admit of the process being used upon a large commercial scale, then the electrolytic methods of manufacturing aluminum would have to be relegated to the same fate that has already overtaken the



PLAN OF THE PITTSBURGH REDUCTION COMPANY'S WORKS.

sodium method of reduction. But, in the light of what I have already said, I venture here to predict a long life and a happy one yet for the electrolytic methods of manufacture of aluminum.

In closing, I wish to acknowledge my indebtedness to Prof. Joseph W. Richards, of Lehigh University, not only for personal statements and suggestions, which I have embodied in this lecture, but also for data from his admirable book on aluminum. It is the first work on the subject printed in the English language, and I prophesy that it will always hold an authoritative position among the best treatises on the metallurgy and properties of aluminum, a place akin to that held by Percy's "Metallurgy of Iron and Steel."

MEETING 412.

The 12-Inch Rifled Mortar.

BY LT.-COL. S. M. MANSFIELD.

The 412th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, February 26th, at 8 P.M., President Walker in the chair.

After the reading of the records of the previous meeting and the election of new members, the President introduced Lt.-Col. S. M. Mansfield, U. S. Corps of Engineers, who read a paper on "The 12-Inch Rifled Mortar."

Col. MANSFIELD said: Our army officers have formulated a system of coast defence, which meets the approval of Congress, for at its last session a small sum was appropriated with which to begin operations, and money with which to purchase land for batteries at some of our principal sea-ports.

Active operations are now in progress for the defence of the harbors of New York, San Francisco, and Boston. Here in Boston we are negotiating for the purchase of land at and near Grover's Cliff, a head-land overlooking Broad Sound in the town of Winthrop. The selection of this promontory meets the approval of all familiar

with the approaches to Boston harbor, as well as of those interested in the locality. Most everyone hereabout has a general idea of what constitutes a fortification, for we have several forts in the harbor, and no doubt it is expected a handsome structure will be erected there, symbolical of the greatness of our republic, and expressive of the majesty and power of government.

The purchase of another tract of land not far removed therefrom, near the swamp in Winthrop, through which ebbs and flows the little stream called Belle Isle Inlet, which does not border upon the sea, which does not command a view of Broad Sound or of the approaches to Boston harbor, and even has a high hill intervening, has excited a great deal of curiosity to learn what is to be the character of the work to be erected there. I am now asked, if we shall build there a work like Fort Warren or Fort Independence. Nothing of the kind, I answer, for such works (and they are to be found in nearly every sea-port on the coast) are obsolete; they were designed and constructed to meet conditions which no longer exist, and which the advent of modern engines of warfare have entirely changed. We shall build no more castellated forts of masonry with guns concentrated in casemates, tier upon tier, surmounted with a tier of guns in barbette. Until these old forts are greatly modified to meet the present requirements, they may be looked upon as of little defensive value. They are rather picturesque features in the land or water scape at present, and after a while will be interesting as reminiscences of the past.

Modern conditions require the separation of guns into small batteries, occupying advantageous positions to command the approaches and anchorages. The guns will be protected by earth parapets rather than masonry walls, and will be formed in a manner to be as little conspicuous as possible in the surrounding landscape, so as to avoid offering a definite target to the enemies' gunners, and they will occupy positions where the fire from all if possible can be concentrated upon any point likely to be occupied by the enemies' vessels. Invisibility is almost essential now in protecting coast-defence guns, and is more valuable than the protection afforded by intercepting a mass of iron, masonry, or earth to receive the hostile shot. The introduction of smokeless powder will aid us greatly in securing this valuable kind of protection. Mortar batteries for vertical fire will be entirely masked

from view as they can be covered by elevations, by trees, by the natural features or inequalities of ground, or sunk in pits, thus avoiding any change in the appearance of the land or sky line. It is for this reason we are acquiring this tract of land in Winthrop, a locality screened from view to an enemy seeking to enter Broad Sound. We propose to construct here two batteries for 12-inch B. L. rifled mortars, to contain sixteen mortars in each, and intend to complete one of them the coming season, to be in readiness for the mortars now building for it.

The Act of Congress of March, 1885, provided for the organization of a Board with Mr. Endicott, late Secretary of War, as president, to be composed of two engineers and two ordnance officers of the army, two naval officers, and two civilians to examine and report upon our fortifications as to the character and kind of defences best adapted for each port, with reference to armament, etc. This Board adopted the views held by the Army Board of Engineers, and recommended 581 high-power guns of all calibers.—8, 10, 12, and 16 inch—and 724 heavy rifled mortars for our principal sea-ports. For Boston they recommended 45 guns and 132 mortars, a proportion of one to three, which evidences the high estimation in which the mortar is held today. The recommendation was due to the modern improvements made in the gun and its mounting, and was doubtless a surprise to those familiar only with the old-fashioned mortar.

I propose to tell you what a 12-inch B. L. rifled mortar is, showing you the reason for so extensive an employment of it in the new system of land defences, and how it is disposed in battery, and the part it is intended to play in future naval attacks upon coast cities, naval stations, and dock yards. I believe the subject will be interesting to many here present, for much has been put before the public relating to high-power guns, rapid-fire guns, machine guns, etc. in the newspapers and magazines during the past year or two, and the rifled mortar has been quite overlooked.

The mortar is a short cannon for throwing shells, containing usually explosives, at high angles of elevation, from 45° to 60° , providing what is called vertical fire, in contradistinction to the fire of long guns, usually made at low angles. The mortar, so called from its similarity to the mortar for pulverizing, has retained its familiar shape from the earliest ages, and is believed to have been the first gun

used. It has been changed from time to time in the form of its chamber, projectile, etc., but its general appearance has not been materially altered till recently. The mounting of the mortar and means of pointing and manœuvring are extremely primitive, and any accuracy of fire with it is simply impossible. Mortar fire, however, has been considered an important element in the bombardment of cities and areas of large extent, and one or more mortars have been furnished to all our sea-coast forts for use against naval attacks, but practice with it is so erratic that it finally dropped almost into disuse and received hardly any attention in military discussions. High-angle fire has again come prominently forward by reason of great improvements made in the arm and in its mounting, and it is now considered in some respects superior to other guns for sea-coast defence, but it in no way supercedes the use of horizontal fire guns, which have their distinctive field of usefulness.

The improved mortar of today is almost an entirely different weapon. It is difficult to see any resemblance in it to the old mortar or to the pulverizing mortar, the parent utensil from which the name is derived. The chief point in common is the discharge of the projectile at a high angle of elevation, the new arm being greatly the superior in range, precision of fire, and destructiveness.

The 12-inch B. L. Rifled Mortar is made of cast iron of the best quality, hooped around the powder chamber with bands of steel, shrunk on in two layers, giving it a girth of about 11 feet. It is 10.3 feet long over all, and has a 9-caliber bore 12 inches in diameter, rifled with an increasing twist for six feet of its length, and is loaded at the breech through a mechanism precisely like that applied to horizontal fire guns. In its mounting provision is made for taking up the recoil gradually instead of rigidly holding the piece as in the case of the old mortar mounting; and provision is also made for loading in a horizontal position. The mounting consists of a small carriage, upon which the trunnions rest, which moves on a slide inclined at an angle of 60°, which in turn is supported by a horizontal platform, rotating on a live roller ring. The carriage is of steel with trunnion beds and sockets for the upper ends of the recoil rams. The slide consists of two steel frames bolted to the upper part of the platform, and to these frames the recoil cylinders are fixed. The platform is built up of girders and transoms of steel. Training gear, for traversing the

platform, and elevating gear, permitting of elevations of 45° to 75° , are also provided. The hydropneumatic cylinders are of steel; each has two chambers, one for the ram, the other for air; they are connected by automatic recoil valves, and a by-pass valve, operated by levers, serves for elevating the gun into firing position. A loading crane is attached to the carriage, and a small hand-pump is provided to supply leakage in the air-chamber and to serve for manœuvring the gun when not firing. The mounting thus described is the English (Anderson), and is typical of all. The Russian (Raskasoff) is similar, but instead of the hydropneumatic cylinders for returning the gun to the firing position the Belleville springs are used.

The carriage obtained from abroad for testing the 12-inch mortar now at Sandy Hook, New York harbor, is of the Russian type; but as it was doubtless constructed for the 11-inch howitzer, the largest gun of this kind then, it was found insufficient to permit our completing the required tests. This gun has been fired 227 rounds out of the 400 rounds intended to be fired, and with charges up to 82 pounds of pebble powder, giving an initial velocity of 1200 feet with a pressure on the powder-chamber of 31,000 pounds per inch. The range attained is 10,480 yards, or 5.95 miles, with a muzzle energy of 5796 foot-tons. Few tests have been made for precision of fire owing to defects in the carriage and in the foundation. When these are remedied, as they soon will be, the firing will be resumed. It has already been determined for this gun to use 80 pounds of powder, which gives an initial velocity of 1152 feet a second, with a shell weighing 630 pounds and a pressure of 28,000 pounds per square inch on the walls of the gun.

To repel a naval attack from the land, three classes of weapons will be employed,—guns, sub-marine mines, and torpedoes. The torpedo, however, is still in the experimental stage, and may or may not be developed into a serviceable weapon. I am myself extremely sceptical regarding its practicability. Guns and sub-marine mines, however, are absolutely necessary in any system of defence. Guns permanently mounted in commanding positions are always ready for service. Sub-marine mines are laid when hostilities are imminent, under the over-shadowing protection of the guns, and are intended to obstruct channels, and necessarily are a passive defence, requiring the ships to come to them. Alone they will not bar the channels,

for they can be countermined or removed unless flanked by rapid-fire guns directed upon boat parties undertaking to tamper with them. Neither will guns alone preclude the passage of ships, for ships can run past batteries without serious injury, as has been proved by numerous instances. It is necessary, therefore, for an enemy to silence our batteries, and to do so ships must come within range of our guns. Now, a modern battle-ship is a pretty formidable thing; she is designed to take her place in line of battle to fight anything that floats, but not designed to attack shore batteries armed with the rifled mortar. The impracticability of combining all the desirable qualities in one type of vessel has led designers to give prominence to one or more qualities to the sacrifice of others perhaps equally desirable. Protection must be provided for both the buoyancy or life of the ship, and for the armament and men. The "Nile" and the "Trafalgar," now building, will presumably be the best ships of the English navy. They have vertical armor 20 inches thick at and below the water line. Forward and aft a heavy steel deck slopes down to the ram and stern post. Four heavy guns are carried in two turrets, and there is a central box battery above an armored steel deck, which covers the citadel. Like most ships they are designed to carry their batteries in turrets and barbettes, and are necessarily open to projectiles from above, having only a slight overhead protection against shrapnel, machine fire, and the explosion of shell. No ship has yet been designed to encounter shore batteries having vertical fire, and it is extremely improbable that any will ever be constructed.

If we could mount our high-power guns on elevations sufficiently high to reach a vessel's deck by depressing the muzzles, it would not matter how heavy was the vertical protection on her sides, but we can rarely find suitable elevated sites, and our high-power guns have too flat a trajectory. So, in order to reach the deck of the ship where it is vulnerable, we must employ vertical fire, and the mortar furnishes the means most admirably. The only argument urged against it is want of precision of fire; but as we shall soon see this objection is not a serious one, even if it exists at all. The application of rifling, improvements in mounting, in the carriage, the use of the position finder, the power of masking the battery out of range and thus securing the perfect service of the guns without confusion, and the ability to employ large numbers of mortars, makes vertical fire a most impor-

tant element in land defence. By this fire the deck of a vessel is reached, and it is here the most destructive effects are produced. The deck of the modern battle-ship has scarcely more than three inches of iron or steel protection, and it is easily penetrated by the shells from the heavy mortar. I will leave to your imagination to picture the result of the explosion of a shell in the vitals of the ship, where are the magazine, the boilers, and machinery.

During the Russo-Turkish War (1877) a six-inch shell from a Russian mortar battery on the Danube penetrated the deck of one of the Turkish sea-going monitors, exploded in the magazine, and sunk it with 17 officers and 200 men. Even should the shell not penetrate the deck but explode upon contact the effect would be disastrous, as the force of explosion would be among the guns and men, and increased by its confinement between the bullwarks. The plan of sinking the deck to the level of the water is the most favorable condition for this kind of fire, and I may say that the officers of the navy are beginning to recognize the defect, and a recent writer strongly advocates the flush deck for future vessels.

The considerations, then, which governed the Fortification Board in recommending so large a proportion of mortars for our sea-coast defence are :—

1st. Because the blow is struck where it will be most effective, and where no armor can be placed to resist it.

2nd. Because of its range and accuracy, due to rifling and improved mounting.

3rd. Because the fire cannot be returned in kind, and therefore cannot be silenced.

4th. Because of the relatively small cost of mortars compared with guns, both to manufacture and to cover against an enemy's fire, an advantage which permits the use of a large number of mortars without too great expense. The 12-inch mortar costs \$8000, while the gun of the same caliber costs \$50,000, and the cost of emplacements are respectively \$10,000 and \$225,000.

In vertical fire the projectile leaves the gun at an angle of about 45°. It meets with resistance from the air and from gravity, which diminish its velocity. At the highest point of the trajectory, gravity still acting, it changes its direction towards the earth, and the air pressure acts in a contrary direction. The projectile, continuing its

descent, increases in velocity till the opposing forces are in equilibrium, when the velocity becomes constant. This final velocity, as it is called in theory, can never be reached in practice. An approximation to this final or greatest velocity is desirable, and the projectile should be made to attain the highest altitude for any given range.

Now, since the velocity of the projectile through its descending trajectory cannot be increased beyond what is due to gravity, which of itself is small, varying as the square root of the height fallen through, we must increase the energy of impact, which is measured by the product of the mass into the square of the velocity ($M V^2$) by adding to the weight of the projectile, and this is precisely what rifling does, for in the rifle we use an elongated projectile or bolt instead of the spherical shell as of old, and consequently can add very materially to the weight of metal. The 12-inch round shell weighs 216 pounds (the cube of the diameter); the corresponding rifle shell weighs 625 pounds. Here is a gain of 200 per cent. It requires $12\frac{1}{2}$ to $14\frac{1}{2}$ foot-tons of energy per inch of circumference of shot to pierce three inches of wrought iron, and by the following table of practice, showing the destructive energy of the 12-inch rifled mortar at different ranges and elevations, it will be seen that for a range of one mile and upward the fire becomes dangerous. It will be impossible to state with accuracy the thickness of various kinds of armor necessary to resist a certain energy of impact, stated in the customary manner of foot-tons. A great many tests have been made, but I am not aware of any complete table of data from which, by inspection, one could say anything very definite. It is said a forged steel and compound armor plate 5 inches thick will be severely strained by an impact of 1200 foot-tons. Now, in the experiments of Krupp, in Germany, to which I shall allude further on, a velocity of impact of 751 feet is recorded, with a shell weighing 661 pounds, the corresponding energy of impact would be 2912 foot-tons.

Another merit of rifling is that it vastly increases the range. The old 13-inch sea-coast mortar, with full charge of 20 pounds, gives a range of 4200 yards, of which not more than 2200 yards would be effective against a three-inch deck. For the rifle the figures are 80 pounds, 10,450 yards and 7200 yards respectively. It is this feature which is so important in opposing distant bombardment by modern guns on ship-board.

A third advantage of rifling is increased precision of fire, and in this connection I present two tables of practice, which show something remarkable, one German the other Russian, but both with the 11-inch Howitzer, as the gun is called abroad. In the trials last fall at Mep-

GERMAN PRACTICE WITH 11-INCH MORTAR.

Date.	Number of Shots.	Elevation.	Charge.	Projectile.	Range.	Extreme Dispersion.		Mean Dispersion.	
						Long.	Lat.	Long.	Lat.
		°	Lbs.	Lbs.	Yds.	Yds.	Yds.	Yds.	Yds.
1879	5	58	13	506	1,993	36	5	11.9	1.6
	5	58	19	759	2,158	12	13	5.4	3.3
to	8	58	33	759	4,019	46	15	13.0	4.7
	10	45	42	475	8,513	145	24	35.0	4.5
1887	10	45	62	475	10,787	130	54	36.2	10.4

RUSSIAN PRACTICE WITH 11-INCH MORTAR.

	Elevation.	Charge.	Projectile.	Range.	Probable Deviation.	
					Long.	Lat.
1885	43°20'	36.1	477	5,668	24 Yds.	4.4 Yds.
		46.9	988	7,412	28.3 "	6.5 "
		18.0	559	2,343	17.6 "	3.3 "
		27.1	559	3,597	13.2 "	2.2 "
		36.1	559	5,014	19.8 "	3.3 "
		45.1	559	6,431	26.2 "	4.4 "

FALLING ENERGY OF A 12-INCH RIFLED MORTAR PROJECTILE.

Range.	Foot-Tons Per Inch of Circumference.		
	45°	60°	75°
Half Mile.....	4.9	7.3	8.5
One Mile.....	9.7	14.6	17.1
Two Miles.....	19.4	29.2	34.1
Three Miles.....	29.1	43.7	51.2
Four Miles.....	38.9	58.3	68.2
Five Miles.....	48.6	72.9	....

pen, the last of a series of firings by Krupp, extending through a period of twelve years, the practice was simply wonderful, and but for authentic records would be past belief. The gun used was the Krupp mortar of latest construction of 11.27 inches bore, and weighed 11 tons. The weight of mounting was 14 tons, while the weight of the bed on which it was placed was 45 tons. The projectiles were armor-piercing shells of 661 pounds, and the charges varied from 25 to 40 pounds of pebble powder.

. The horizontal armor-deck target measured 52 x 13 feet, and was composed of a total thickness of $3\frac{1}{2}$ inches of iron backed with wood, and ribs of iron representing exactly the deck of a modern battle-ship, and supported five feet above the ground. A series of ten shots were fired with an elevation of 45 degrees. The shell weighed 661 pounds, the charge of powder 25 pounds, and the range was 3870 yards ($2\frac{1}{4}$ miles). The greatest longitudinal deviation was 95 feet, the greatest lateral deviation was 27 feet. One hit was made with a striking velocity of 610 feet a second, and an angle of incidence of $46\frac{1}{2}^{\circ}$, not varying much from the angle of elevation of fire. The target was pierced very nearly in its center, and the shell embedded itself in the ground five feet deep.

Another series of shots of sixteen was fired with an angle of elevation of 65° with shell of the same weight as above, and a powder charge of 33.8 pounds, the range being the same, 3870 yards. The greatest longitudinal deviation was 105 feet, the greatest lateral deviation 88 feet, and one hit was obtained the longitudinal deviation of which was 5 feet, and the lateral deviation 20 inches. The striking velocity was 751 foot-seconds, and angle of incidence about 66° . Once more the target was pierced, the center was depressed nearly two inches, 13 rivets were displaced, the supports were seriously bent, and the projectile was found unharmed 15 feet to the rear of the hole in the target, and four feet deep in the earth.

Of these two series of 26 shots in all, 20 hits would have been made had the target been of the area of the deck of a man-of-war. These tests were conducted under the most favorable conditions of the atmosphere, and with mechanical perfection and skill of the highest degree.

Mortar batteries are of a very simple form. An ample thickness of earth is necessary to cover the magazines and quarters for the

garrison against projectiles from a distance, which would be likely to reach the battery through the descending portion of their trajectories, —an angle of descent scarcely exceeding 15, or possibly 20, degrees. They would be masked from the fire of an enemy's ship by the natural inequalities of the ground, by trees and shrubbery, for a view of the ship is not necessary for this service, which may be governed from a distant point by telegraph. A single battery is designed to accommodate a number of mortars, in order that many projectiles may fall near together when a number or all are fired at once. By placing four mortars together in a pit, and four pits in such a manner as to make the best arrangement for the magazines and bomb-proofs in their midst, a compact battery of sixteen mortars convenient for the command of a single officer results. The longitudinal and lateral separation of the pits must be sufficient to afford this interior space for magazines, etc., but they must not be separated so far that the shots will fall apart so as to leave an area of safety between them. Lateral dispersion being much less than longitudinal dispersion, a narrower limit is admissible for separation of the pits across the plane of fire than in a direction parallel to that plane. These conditions are fulfilled when the centers of the outer mortars in each pit are on a circle of 150 feet radius, giving a lateral separation of the outer mortars in each pit of 140 feet, and a longitudinal separation of 265 feet. The arrangement of the magazines is simple, and the galleries convenient for the service of the battery. Nearly all of the work is done under cover except actual loading, the fire of the battery being controlled by the officer within, stationed at the telephone instrument with the key of the firing battery at hand. The sixteen shots being fired under the same conditions should fall in relative positions corresponding to the mortars themselves. From the table of firing records available, but which unfortunately are limited, it is found that a rectangular area 28 feet wide and 162 feet long will contain 50 per cent of the shots fired from a single mortar. By cutting out of tracing cloth or transparent paper areas of this dimension of the same scale as the map, and laying them thereon in proper relation to each other, it will be seen how completely the area under fire of the battery is covered. The combined area of fire of one sixteen-gun battery is about 300 x 800 feet at a range of $4\frac{1}{2}$ miles. Now, as the battery can doubtless be fired every ten minutes, it is cal-

culated that a ship within its range would be hit from two to nineteen times an hour. It is clear that it would be a reckless commander who would subject his ship to a single chance shot even. By multiplying the batteries the risk in occupying the field is enormously increased.

The mortar battery is easily constructed ; besides some little skilled labor in fitting doors, lights, ventilators, etc., there is no work about it but what can be readily done by common labor under intelligent supervision, and it is therefore cheaply constructed. I have great faith in the rifled mortar for defence of our sea-coast because of its simplicity ; it is easy to construct and handle, and hence may be quickly provided should occasion suddenly arise,—an exigency more than likely with us, who are accustomed to neglect the lesson of experience and rest satisfied in fancied security. It can be constructed in several of our large iron establishments at the present time without a great outlay of time or money for a special plant, and emplacements can be provided with even greater facility.

Should we be so unfortunate as to be suddenly involved in war in our present defenceless condition, no weapon can be so readily provided, or one which will be so efficacious to ward off hostile shell from our principal cities, and none more economical to construct or to serve.

It would be a wise policy, however, to provide against such a contingency by having at each of our sea-ports an ample number of these guns, since they can be obtained so cheaply, and their presence would go so far toward avoiding hostilities. An ounce of prevention is worth a pound of cure.

MEETING 413.

Chemical Precipitation of Sewage.

BY MR. ALLEN HAZEN.

The 413th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, March 12th, at 8 P.M., Prof. T. M. Drown in the chair.

After the reading of the records of the previous meeting, the chairman introduced Mr. Allen Hazen, chemist in charge of the

Lawrence Experiment Station of the Massachusetts State Board of Health, who read a paper on the "Chemical Precipitation of Sewage."

Mr. HAZEN said: If sewage is allowed to stand for a few hours, a portion of the organic matter will settle out; but the greater part is either too finely divided to separate in a moderate length of time, or is in solution. By adding certain chemicals to the sewage, an inorganic precipitate is formed, which settles rapidly, and carries with it nearly all of the suspended matter, and also a portion of the dissolved matter. This is the *chemical precipitation of sewage*. Nothing definite is known of the chemistry of the process which makes insoluble a portion of the dissolved organic matter, but it is probably similar to the use of mordants in dyeing for fixing soluble colors.

Chemical precipitation is practically carried out in tanks or settling basins, four to seven feet deep, and of sufficient capacity to hold one-half of the daily dry weather flow of sewage. The sewage usually flows continuously into one end of a series of tanks after being mixed with the chemicals, and, passing very slowly through the tanks, deposits its suspended matter, and finally flows over a weir at the lower end in a clarified condition. The tanks are drawn off in regular order, from time to time, for the removal of the deposit or sludge, only one usually being empty at a time.

It has been claimed that this deposit would make a valuable manure, but experience has not borne out the claim, for from 70 to 90 per cent of the total fertilizing value of the sewage is in solution, and incapable of economical precipitation. As a matter of fact, chemical precipitation works instead of selling their sludge at a profitable price have been forced to dispose of it in the cheapest way possible.

A series of experiments upon the chemical precipitation of sewage has been made at the Lawrence Experiment Station to find the exact action of the different precipitants, and in determining the most suitable proportions of the various chemicals and their respective merits.

The substances best adapted and most commonly used for chemical precipitation are lime and the salts of aluminum and iron.

I have endeavored, in the following-described experiments, to determine, first, the best method of using each chemical substance, and to establish, if possible, some relation between the composition of the sewage and the amount of precipitant which will give the best

result, or as good a result as a larger quantity; and, second, to compare the effect of equal values of the different precipitants upon the same sewage, after finding, by the first experiments, how to use each with the greatest advantage. The experiments also give an idea of the amount of matter which can be removed by chemical precipitation under favorable circumstances. The observations have been confined to the composition of the sewage and of the effluent, neglecting the sludge altogether.

It was decided that the only way to get entirely satisfactory results was to make several parallel experiments on the same sample of sewage. To accomplish this, barrels were set so they could be filled from one of the sewage tanks. The tank was filled with sewage and thoroughly mixed, and, while it was still being stirred, the barrels were filled from it and chemicals added as desired. One barrel was left to settle without chemicals, for comparison. It is possible, in this way, to get several comparable results. The barrels were 30 inches high, and held about 50 gallons each. As the capacity of each was accurately known, it was easy to compute the amount of precipitant for each barrel at any desired amount per 1,000,000 gallons.

The sewage in each barrel was thoroughly mixed with the chemicals, and allowed to settle. A sample of the effluent above the sludge was then drawn from a tap about 10 inches from the bottom, first letting it run freely for a minute, so that the sample fairly represented the contents of the barrel, above the very thin layer of sludge.

Four series of experiments were made with different amounts of lime. In each case, seven barrels were filled from the same mixed tank of sewage, and different amounts of lime added, making a regular series, every barrel having more lime than the next below. These series were plotted and studied in detail.*

Up to half a ton of lime very little calcium carbonate is precipitated. It is held in solution by the excess of carbonic acid. From this point it increases rapidly as far as the experiments were carried. The amount which might be precipitated by increased amounts of lime is limited by the amount of carbonic acid present, and for the sewages used could not exceed 35 to 40 parts per 100,000. It was found that the maximum precipitation of calcium carbonate is not reached when

*The details of these experiments, with diagrams of the results, are given in the report of the Massachusetts State Board of Health on Water Supply and Sewage, Vol. II.

the lime is equal to the carbonic acid ; for, even without free carbonic acid, the sewage holds in solution a very considerable quantity of calcium carbonate.

With quantities of lime too small to cause precipitation of calcium carbonate, the result is little better than that obtained by settling sewage without chemicals. With larger quantities of lime, and increasing precipitation of calcium carbonate, there is a regular improvement in the effluent until the point is reached when the lime is equal to the carbonic acid. The addition of a larger amount of lime than this does not usually remove more organic matter, and, indeed, the effluent frequently contains somewhat more impurity than with a smaller quantity. This may be due to the solvent action of caustic lime, which is only present when the lime is in excess. An increase of lime does, however, kill the bacteria, the effluent being practically sterile when a very large amount of lime is used.

It thus appears advantageous to use an amount of lime which exactly suffices to form normal carbonates with all the carbonic acid present. The quantity required can be calculated from the amount of carbonic acid and alkali present in the sewage, as found by titrations, which can be made in a few minutes, and with very simple apparatus.

Copperas, or ferrous sulphate, occurs in commerce in a nearly pure form. Its value for the treatment of sewage depends upon the precipitation of ferrous hydrate or carbonate. Preliminary experiments indicated that it is necessary to add lime with copperas, in order to get the best result. Experiments were made to ascertain how much lime is required and the effect of different amounts of copperas, and whether the sewage should be first mixed with the lime or the copperas. Seven barrels were filled with sewage from the same large tank. To the first was added a certain amount of copperas, and to the other barrels the same amount of copperas, and different amounts of lime, forming a regular series, as with lime alone. In other series of experiments different amounts of copperas were used.

It was found that, when copperas is added to sewage alone, no precipitation takes place, and the result is no better than when sewage settles alone. The addition of enough lime to combine with the excess of carbonic acid over the amount required to form bi-carbonates, and to combine with the sulphuric acid of the copperas, is neces-

sary for precipitation; for, while sewage is alkaline, its alkali is all in the form of bi-carbonates, and alkali as normal carbonate or hydrate is required to precipitate the iron. When this amount is added, the acid number with phenolphthalein will be zero. To insure a rapid action, a little more than this should be added. No better result is obtained when more lime is used. If much less is used, the iron will not be precipitated, and the result will be the same as if the sewage had been settled without chemicals.

The amount of lime required by any particular sewage can be calculated from a titration of the sewage with standard alkali solution, using phenolphthalein as indicator, but it is practically more convenient to test the sewage with phenolphthalein after mixing with both lime and copperas.

The test with phenolphthalein shows instantly whether enough lime has been added, and it can be used by anyone. It consists of adding a few drops of a solution of phenolphthalein in alcohol to a portion of sewage in a small dish. If enough lime is present, it will be turned blood red, while, if enough lime is not present, it will remain uncolored. The smallest amount of lime which will give the reaction gives as satisfactory a result as a larger quantity.

This reaction is equally useful in the precipitation by lime of acid sewage containing iron from manufacturing waste. In this case, the copperas is carried by the sewage, and the addition of lime is required to neutralize the acid and precipitate the iron, thus rendering it available. For this reason the conditions of successful precipitation of such sewage, and the results obtained, correspond with the copperas treatment rather than with the lime treatment. But in case the sewage contained no iron in solution, the phenolphthalein reaction is obtained long before enough lime has been added; and, to get the best results, the quantity of lime must be regulated as has been described.

It was found that with increasing amount of copperas, with the proper amount of lime in each case, the effluent was regularly better, but nearly all the advantage was obtained with half a ton. One hundred pounds of copperas gave a result very slightly better than sewage settled alone.

In all of these experiments the sewage was first thoroughly mixed with the lime water, and then the copperas added. Experi-

ments were made to see if a better result could be obtained by mixing the sewage with the copperas first, and then adding the lime, or if as good a result could be obtained by precipitating the copperas with lime, and adding the precipitated ferrous hydrate to the sewage.

It was found that with 500 pounds of copperas and an equivalent of lime the best result was obtained when the sewage was first mixed with the lime, *i. e.*, in the way the preceding series had been made. With 1000 pounds of copperas the difference between these two ways of mixing was insignificant. When the copperas was precipitated by lime before adding it to the sewage, the result was unsatisfactory, both when the amount of lime used was the same as in other experiments, and when only enough was used to combine with the sulphuric acid of the copperas. We may conclude, then, that neither of these ways of mixing is more advantageous than that which was used for the preceding experiments.

Ferric salts have the advantage over ferrous salts in that ferric hydroxide is more readily precipitated and more completely insoluble than ferrous hydroxide.

Experiments were made to determine whether it is necessary to add lime to obtain the best results with ferric salts, and, if so, how much should be used; and also to find the effect of different amounts of ferric oxide.

The salt used for these experiments was ferric sulphate, but there is every reason to suppose that exactly the same results would be obtained with ferric chloride containing an equal amount of iron. The method of making these experiments in series, with regularly varying amounts of chemicals, was the same as that used for lime and copperas.

It was found that the influence of lime on the result is very small. With 200 pounds ferric oxide, the result was slightly better when lime was used; but the improvement does not correspond with the increased cost. With 400 pounds of ferric oxide, the lime had almost no influence. With 300 pounds ferric oxide, no better result was obtained by mixing the sewage with 1000 pounds of lime before adding the ferric sulphate. When the lime was added to the sewage after the ferric sulphate, the result was not quite so good as when no lime was used.

These results show that, while ferrous salts are only precipitated by normal carbonates or hydrates, ferric salts are also precipitated by

bi-carbonates, and in presence of free carbonic acid. For this reason the reaction with phenolphthalein, which proved to be of so much importance in precipitation with copperas, is of no value with ferric salts, and the addition of lime to an ordinary alkaline sewage is quite useless. The experiments show that, as with copperas, the more of the precipitant used the better is the result.

Aluminum sulphate or crude alum is now made for use in the dye-house for decolorizing peaty waters, and for sewage precipitation. Its action upon sewage is analogous to the action of ferric sulphate. There is every reason to suppose that aluminum chloride containing the same amount of alumina would give exactly the same results as the sulphate.

Experiments were made to determine whether lime could be used advantageously with alum, and to find the effect of different amounts of alum.

It was found that, as with ferric sulphate, lime has little or no effect. With lime the precipitation is a little more rapid, but the short time gained by its use would hardly compensate for the extra cost.

The result with 1000 pounds to the 1,000,000 gallons is, on the whole, somewhat better than with 500 pounds, but the difference is much less marked than with corresponding quantities of copperas or ferric sulphate.

The foregoing experiments indicate that a certain definite amount of lime gives as good or a better result than either more or less; and that, in general, the more copperas, ferric sulphate, or alum used the better the result; and that ferric sulphate and alum usually require no lime for complete precipitation, while with copperas a definite amount of lime must be used.

It now remains to compare the results obtained with the best amount of lime, and with equal value of the other chemicals, upon the same sample of sewage when used under the most favorable conditions. Two series of experiments were made in this way.

In calculating the cost for chemicals the following prices have been taken:—

Lime, ...	per ton, \$9.00
Copperas, ...	" 10.00
Sulphate of alumina, ...	" 25.00
Ferric oxide as sulphate, ...	" 30.00

One hundred gallons of sewage daily for each inhabitant is assumed in calculating the annual cost. Of course the figures would have to be corrected for particular places, taking into account the prices and composition of the chemicals used, and the amount and composition of the sewage.

The average results of these comparative experiments upon the same sewage were as follows:—

THE PER CENT OF SOLUBLE ORGANIC MATTER REMOVED BY CHEMICALS OF EQUAL VALUE.

Chemicals Used.	Thirty Cents.				Forty Cents.	
	Lime.	Copperas and Lime.	Ferric Sulphate.	Alum.	Ferric Sulphate.	Alum.
Soluble albuminoid ammonia removed	22	29	32	20	41	29
Soluble loss on ignition removed.....	4	21	28	30	45	20
Turbidity removed.....	77	70	81	77	83	77
Bacteria removed.....	93	38	92	91	93	93
Yeast removed.....	92	98	95	82	95	90

If we take the percentage of albuminoid ammonia removed to represent organic matter, we find that, in addition to all the suspended matter, the following amounts of soluble organic matter have been removed:—

Soluble Organic Matter removed by Chemicals at Different Costs.

With lime costing 30 cents per inhabitant, annually, .	22 per cent.
With copperas and lime costing 30 cents, ...	29 per cent.
With ferric sulphate costing 30 cents, ...	32 per cent.
With aluminum sulphate costing 30 cents, ...	20 per cent.
With ferric sulphate costing 40 cents, ...	41 per cent.
With aluminum sulphate costing 40 cents, ...	29 per cent.

The lime process has little to recommend it. Owing to the large amount of lime water required, and the difficulty of accurately adjusting the lime to the sewage, very close supervision would be required to obtain a good result, and even then the result is inferior to that obtained in other ways.

Precipitation by copperas is also somewhat complicated, owing

to the necessity of getting the right amount of lime mixed with the sewage before adding the copperas. When this is done, a good result is obtained. The amount of iron left in the effluent is much greater than with ferric sulphate, owing to the greater solubility of ferrous hydroxide.

Ferric sulphate and alum have the advantage over both lime and copperas, that their addition in concentrated solution can be accurately controlled, and the success of the operation does not depend upon the accurate adjustment of lime or any chemical to the sewage.

The results with ferric sulphate have been, on the whole, more satisfactory than those with alum. This seems to be due in part to the greater rapidity with which precipitation takes place, and in part to the greater weight of the precipitate. It is probable, from the greater ease with which ferric sulphate is precipitated, that it would give a good result with a sewage that was not sufficiently alkaline to precipitate alum at once.

It is quite possible that the same process would not give equally good results upon all kinds of sewage. Special sewages may require special treatment. For this reason, and also on account of changes in the prices of the several chemicals, it is impossible to say that one precipitant is universally better than another.

In the later experiments from 25 to 43 per cent of the soluble organic matter, as shown by the albuminoid ammonia and loss on ignition, was removed by copperas, ferric sulphate or alum, costing from 30 to 40 cents per inhabitant annually. In addition to this, all of the suspended matter was removed. The average proportion of suspended organic matter in Lawrence sewage, as shown by a very large number of analyses, is 45 per cent of the whole amount. If we can remove 30 per cent of the soluble organic matter, and all of the suspended, we shall leave only 70 per cent of the 55 per cent soluble organic matter, or 38 per cent of the whole; while, if we remove 40 per cent of the soluble organic matter, the amount left will be only 33 per cent of the whole.

Of the other substances present the insoluble inorganic matters, mainly sand, are removed almost completely, while the soluble salts, including chlorine and free ammonia, are not affected in the least, excepting that the acid of the precipitant remains in solution, in combination with the alkali of the sewage. A very large proportion of

bacteria and of the other organisms is removed. This is all that can be done by chemical precipitation.

When a nuisance is produced by sewage in any way the direct cause is usually the development of organisms fed by the organic matter and nitrogen compounds of the sewage. To secure the absence of organisms in any pond or stream, where food is present, is a hopeless task. It thus happens that, while the organisms are the real cause of the trouble, their removal from sewage is often of less importance than the removal of the matter in the sewage on which they feed. The proportion of organic matter removed does not necessarily represent the proportion of food for organisms removed, for some kinds of organic matter are no more suitable food for bacteria than is sawdust for horses. An effluent from a sewage filter, where nitrification is complete, containing 2 per cent of the total organic matter of the sewage, will not serve as food for bacteria, because it has been worked over already by bacteria in the filter, and nearly everything available has been removed. If, on the other hand, sewage is mixed with fifty times its volume of pure water, so that it contains the same amount of organic matter as the effluent, the bacteria will increase enormously for a few days. From this point of view the effluent is many times purer than is indicated by the ratio of its organic matter to that of the sewage.

With sewage precipitation the case is entirely different, for here there is no bacterial action. There is, however, some reason to think that the organic matter left is not so good a food, and therefore not so dangerous as that removed. Sewage settled alone will keep turbid with organisms, and in a day or two masses of zoöglœa (dead or resting bacteria) separate from it. Sewage precipitated by either copperas, ferric sulphate, or alum in suitable quantities has repeatedly remained so clear that the bottom of the barrels could be distinctly seen through more than two feet of liquid, for one week or two weeks. In these cases no flakes of zoöglœa so characteristic of untreated sewage has been seen, and the odor is much less than that of sewage alone.

This question of the quality of the organic matter left by precipitation has not been sufficiently investigated, but the indications are that it is more objectionable than the same amount in the effluents from sewage filtration through sand, but less objectionable than that in sewage.

When untreated sewage is put into a small stream or pond, it often happens that the suspended matters settle out, forming considerable deposits, which, putrefying out of contact of the air, give rise to very offensive gases. It is hardly probable that well-precipitated sewage would do this, for almost no suspended organic matter is present when it leaves the settling tank, and very little soluble matter is precipitated on exposure to the air.

Another nuisance which might be caused by putting precipitated sewage into a stream or pond is the growth of algæ,—green plants fed by the ammonia of the sewage. It may be said, however, that this growth would be no greater than that caused by the crude sewage, and probably not much greater than that caused by filtered sewage; for, in the latter case, while the ammonia is removed, nearly an equivalent of nitrate is formed, and this serves as food for algæ almost as readily as ammonia.

A number of fishes were put into precipitated sewage. In each case the fish died within five minutes. This sudden death cannot be due to the chemicals used, for it was found that the fishes lived for a considerable time in solutions of the chemicals much stronger than those present in the sewage. The fishes died for want of air. Sewage contains no dissolved oxygen, and, if any is absorbed from the air, it is quickly taken up by the organic matter. The precipitated sewage also contains no oxygen.

MEETING 414.

Relative Value of Steam and Street Railways.

BY MR. GEORGE W. MANSFIELD.

The 414th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, March 26th, at 8 P.M., G. W. Blodgett in the chair.

After the reading of the records of the previous meeting, the chairman introduced Mr. George W. Mansfield, of the Thomson-

Houston Electric Co., who read a paper on "Relative Value of Steam and Street Railways."

Mr. MANSFIELD said: When I promised your secretary to prepare a paper, I had in mind, in a general way, a few facts regarding the passenger traffic of the steam railroads and street railroads of our country, which I thought I could gather together to show their relative physical magnitude, political necessity, and social importance. I sent out circulars in a number of directions to elicit information, and hunted up all the books, papers, and clippings which I possessed. After much patience in research and in compiling comparative tables, I must sadly confess an inability to present much of any great interest or importance.

Both steam and street railroads are essential to a nation's welfare. Whether one is more important than the other, it is difficult to say. It cannot be reasoned that the steam railroads have made the nation entirely what it is, since, on the other hand, it is equally true that the great centers which make up the nation would not be so great if it were not for the street railroads.

Please remember that I am discussing this question entirely upon the basis of passenger transportation. The immense importance of steam railroads as freight carriers is for the moment set aside.

Street railroads are of immediate necessity; we need them every day of our lives. They are our horses and carriages. They enable us to obtain every possible social and political advantage. We are swiftly, safely, and cheaply carried to the doors of our friends, our theatres, our lecture halls, our schools, offices, churches, libraries, and elsewhere. Artisans have a cheap method of getting to and from their work, and their field for obtaining work is thus expanded. They promote intercourse; they unite as well as expand. They are the circulating system, so essential to our life and happiness. Congestion is avoided, and our morality improved. Rarely indeed have they even proven unnecessary or superfluous. I venture to assert that there is not today a city in our country that is not suffering for either more or better transit facilities.

What means this cry for rapid transit now going up from almost every great city in our Union? Our personal necessities demand that we travel short distances much more frequently than we travel long distances. The greater the distance the less the travel, and the

shorter the distance, with reasonable expense, the greater the travel. Naturally, if we could travel at tremendous speeds, then distance would not have the tendency to restrain us from traveling. In years to come there is no question that 100 miles will look no greater than ten miles today. The question of running 100 and more miles per hour is being agitated fully and freely and is being discussed everywhere. Mr. Crosby, in a recent paper, has given us some very interesting data in regard to such speeds. Prof. Rowland, of Johns Hopkins University, and Dr. Louis Duncan agree with him that 120 miles per hour is safe and feasible. There is scarcely anyone who looks towards steam for the solution of this problem; and electricity is almost universally conceded to be the power.

The history of the construction and operation of the steam railroads has been easy to obtain, but a similar history of the street railroads has been most trying and unsatisfactory. In so far as I have gone, it has been unique and fascinating.

Sometime in the early part of this century Oliver Evans endeavored to traverse the streets of Philadelphia with a steam road engine. No attempt was made to lay rails. It is thus seen that it was thought of. In 1826, at Quincy, Mass., the first horse railroad was constructed, but not for the transportation of passengers. It served a more glorious purpose. It was used to transport the blocks of granite for the Bunker Hill Monument from the quarry. It was not, however, until 1831 that the first street railroad was incorporated. In that year the New York & Harlem Railroad Co. was authorized to operate cars drawn by horses and the road to be built. The first cars were run in 1832 from Prince Street, New York City, by way of Fourth Avenue to Harlem Bridge. This road, however, had a checkered career, and but little else was done either in New York or elsewhere.

In 1850 scarcely any progress had been made, but in the fifties the real live history of street railways commenced. The first street railroad in Massachusetts, running from Boston to Cambridge, was started in 1854. In Philadelphia the first street railroad was the Fifth and Sixth Street Railroad, which started in 1852. For a long time the growth of street railroads was very slow. This can be seen from Table I, but of recent years it has been tremendous. An industry young in years, with immense possibilities, a social and political

TABLE I. TABLE SHOWING GROWTH BY DECADES OF STREET RAILWAY TRAFFIC IN THE TOWNS AND CITIES OF MASSACHUSETTS.

Name of Road.	Date Opened.	Place Covered.	1860.		1870.		1880.		1890.	
			Popula- tion.	Passengers Carried.	Popula- tion.	Passengers Carried.	Popula- tion.	Passengers Carried.	Popula- tion.	Passengers Carried.
Gloucester St. Ry.....	86	Gloucester.....	10,904	.....	15,389	.....	19,529	.....	24,651	650,692
Holyoke St. Ry.....	84	Holyoke.....	4,567	.....	10,733	.....	21,915	.....	26,637	693,419
Hoosac Valley St. Ry.....	89	Adams & N. Adams.....	6,924	.....	12,090	.....	15,782	.....	26,287	561,532
Plymouth & Kingston St. Ry.....	89	Plymouth & Kingston.....	7,723	.....	7,974	.....	8,617	.....	8,973	544,646
Taunton St. Ry.....	71	Taunton.....	15,376	.....	18,629	.....	21,213	361,592	25,448	767,292
Union St. Ry.....	.....	New Bedford.....	22,300	.....	21,520	.....	26,845	728,035	40,733	3,235,116
Worcester Con. St. Ry.....	.....	Worcester.....	24,960	.....	41,105	304,165	58,291	830,182	84,665	4,361,574
Springfield St. Ry.....	70	Springfield.....	15,199	.....	32,703	67,706	33,240	770,310	44,179	3,628,008
Newburyport & Amesbury H. R. R.....	.....	Newburyport & Amesbury.....	20,588	.....	21,902	.....	23,209	233,973	27,694	1,336,658
Northampton St. Ry.....	66	Northampton.....	6,788	.....	10,160	102,329	12,172	81,489	14,990	307,143
Pittsfield St. Ry.....	86	Pittsfield.....	8,045	.....	11,112	.....	13,364	.....	17,281	306,167
Lowell Horse Ry.....	64	Lowell.....	36,827	.....	40,928	443,677	59,475	791,880	77,696	4,183,392
Lowell & Dracut St. Ry.....	.....	Lowell.....	5,911	.....	8,474	.....	10,127	.....	13,806	320,373
Marlboro St. Ry.....	89	Marlboro.....	22,548	.....	34,429	291,115	46,760	648,370	53,210	1,885,506
Merrimack Valley Horse R. R.	67	Methuen, Lawrence & N. Andover.....	14,779	330,351	21,890	111,014	28,707	117,338	43,086	348,597
Newton St. Ry.....	69	Newton & Waltham.....	9,472	.....	9,061	.....	13,592	16,870	16,870	465,713
Attleboro, N. A. & Wrentham St. Ry	90	Attleboro & Wrentham.....	5,515	.....	11,290	8,479	12,429	236,847	9,118	236,847
Natick & Cohasset St. Ry.....	83	Natick.....	7,805	.....	11,290	.....	12,429	22,037	22,037	506,143
Fitchburg St. Ry.....	86	Fitchburg.....	11,264	.....	12,107	.....	15,054	18,275	18,275	.....
Beverly & Danvers Ry.....	90	Beverly & Danvers.....	4,227	.....	4,968	.....	6,235	.....	9,239	337,000
Framingham Union St. Ry.....	88	Framingham.....	14,026	.....	26,766	.....	49,961	110,645	74,398	3,143,212
Globe St. Ry.....	80	Fall River.....	15,353	.....	18,868	.....	26,331	149,272	35,119	936,170
Haverhill & Groveland St. Ry.....	77	Haverhill, West New- bury, Bradford & Groveland.....	12,344	.....	13,649	.....	20,659	.....	35,681	2,210,706
Brockton St. Ry.....	.....	Randolph, Brockton & Whitman.....	6,778	.....	7,442	.....	16,570	.....	16,723	579,347
East Side St. Ry.....	90	Quincy.....	3,186	.....	3,090	.....	2,896	.....	3,451	27,394
Whitman St. Ry.....	89	Quincy.....	.....	.....	.....	.....	.....	.....	.....	.....
Quincy & Boston St. Ry.....	.....	Wareham.....	299,903	13,364,842	417,685	25,904,332	594,552	63,807,856	705,186	133,530,899
E. Wareham, Onset Bay & Ft. Independence St. Ry.....	.....	Wareham.....	.....	.....	.....	.....	.....	.....	.....	.....
Onset Bay St. Ry.....	.....	Boston, Cambridge, Arlington, Somer- ville, Watertown, Chelsea, Everett, Malden, Medford, Lynn & Boston R. R. Somerville Horse Ry.....	.....	.....	.....	.....	.....	.....	.....	.....
West End St. Ry.....	64	West End St. Ry.....	.....	.....	.....	.....	.....	.....	.....	.....
Chelsea & Boston R. R.....	.....	Chelsea & Boston R. R.....	.....	.....	.....	.....	.....	.....	.....	.....
Malden & Melrose Ry.....	.....	Malden & Melrose Ry.....	.....	.....	.....	.....	.....	.....	.....	.....
Wrentham Horse Ry.....	.....	Wrentham Horse Ry.....	.....	.....	.....	.....	.....	.....	.....	.....
Winnisnet St. Ry.....	.....	Winnisnet St. Ry.....	.....	.....	.....	.....	.....	.....	.....	.....
Lynn Belt Line Ry.....	.....	Lynn Belt Line Ry.....	.....	.....	.....	.....	.....	.....	.....	.....
E. Middlesex St. Ry.....	.....	E. Middlesex St. Ry.....	.....	.....	.....	.....	.....	.....	.....	.....
No. Woburn St. Ry.....	.....	No. Woburn St. Ry.....	.....	.....	.....	.....	.....	.....	.....	.....
Naumkeag St. Ry.....	.....	Naumkeag St. Ry.....	.....	.....	.....	.....	.....	.....	.....	.....
Totals.....	.....	Totals.....	604,722	13,695,193	926,316	27,224,337	1,148,004	68,631,842	1,543,531	164,873,846
Ratio.....	.....	Ratio.....	22.6	.....	29.3	.....	59.0	.....	.....	109.8

necessity, yet passed by and unrecognized for years by brains or capital, is becoming today one of the most forward and important. Growing up right under our very eyes, and entering regularly into our daily welfare, we never seemed to have discussed or mentioned it more than we would other questions of daily monotonous appearance and growth. From quite extensive personal observation, it seems as if most of the street railroads of today were the creations or inventions of local geniuses and aspirants for wealth. Each little company has its own idea of gauge of track; size or shape of rail; how it should be laid; where it should be laid; size, shape, and color of cars; location of stables, car houses, etc.; and, finally, a method of keeping its accounts. This last is of important interest, and I have no hesitation in stating my belief that there are not two street railroad companies in the country who keep their accounts in such shape that they could make comparisons without hours, if not days, of patient compilation. The following units have been used by different companies for basing their income and output,—per horse, per car, per mile of road, per car mile run, and per passenger. With the introduction of electricity, however, a most decided desire on the part of street railroad companies has been shown for a uniform system in keeping account of the operating expenses of their roads. In point of fact, it has become imperative. If all street railroad companies will keep a uniform system of accounts similar to the steam railroads, gas companies, or other large corporations, doing a similar business throughout the country, we will be able to more intelligently discuss these questions in the future. It surely is an end toward which all street railroad managers should work. Undoubtedly the local character of the business has had much to do with this extraordinary diversification. Local capital, as a rule, has governed and controlled. Under such conditions, the necessities for complete and accurate data were not so apparent.

The Massachusetts Board of Railroad Commissioners was established in 1869, and its value is beyond question. There is no State in the Union which issues a more exact and comprehensive report. In this State, therefore, much has already been accomplished. The only other States in the Union that issue any kind of reliable data are Maine, Rhode Island, New York, and Pennsylvania. It may seem strange, but it is nevertheless true, that this industry, which

railroads, and reduce them to any basis whereby they could be compared, and still more difficult whereby any comparison could be made with steam railroads, who kept their accounts on an entirely different plan.

TABLE IV.

Date.	Population.	Increase.	Per Cent Increase.	Passengers Carried.	Increase.	Per Cent Increase.
1850	994,514	.....	....	.....	.....	....
1860	1,231,066	236,552	23.8	13,695,193	.....	....
1870	1,457,361	226,295	18.7	27,224,337	13,529,144	98.8
1880	1,783,085	325,724	22.4	68,631,842	41,407,505	152.1
1890	2,078,625	295,540	16.6	164,873,846	96,242,004	140.2

TABLE V.

Date.	Miles Line.	Passengers Carried.
1882	140,960	289,030,783
1883	149,183	312,686,641
1884	156,497	334,570,766
1885	160,597	351,427,688
1886	168,048	382,284,972
1887	185,047	428,225,513
1888	191,497	451,353,655
1889	202,787	495,124,767

Per cent of increase in Miles Line in 8 years, 43%.

Per cent of increase in Passengers Carried in 8 years, 71.3%.

Per cent of increase in Population in United States in 10 years,—1880-90, 30%.

The facts of the growth of the street railroads throughout the country cannot be obtained. Massachusetts, however, gives some most interesting figures. (See Table I.) In 1850 there were no passengers carried, but in the succeeding decades a most rapid rise. This can be readily seen by Table IV. I have also arranged it so that the per cent of increase of population can be noted. Tables II and III show the same most interesting tale for one decade, but with the addition of the steam railroad traffic. The ratios as shown on Table I show, by decade, the number of times the population of those towns in which street railroads were was carried. As evidence of their local popularity, look at the figures of Table I, and note the Plymouth & Kingston Street Railway, which is operated with electric

TABLE VI.

	Total Square Miles.	Total Acres.	Population.		Miles of Railway Line.	Miles of Railway Line.		
			Total.	Per Sq. Mile.		To Sq. Mile.	To Acre.	To Inhabitant.
Steam Roads — United States.....	3,019,060	1,932,192,000	65,213,107	21.54	.0339	18.75	11,972	404.05
Street Railways in 44 cities with over 50,000 population each....	1,090.11	697,670.4	10,727,343	98.40	15.4	.39	254	39.07
Steam Roads — Massachusetts.....	8,315	5,321,500	2,078,625	249.98	.39	3.99	2,554	997.97
Street Railways — Massachusetts...	.....	.....	1,543,531	.....	.....	....	....	26.70

TABLE VII.

POPULATION AND PASSENGERS CARRIED IN FIVE (5) STATES IN 1890.

1890	Massachusetts.	Pennsylvania.	New York.	Rhode Island.	Maine.	Total.
Population.....	2,078,625	5,400,000	6,500,000	304,284	660,139	14,943,048
Total passengers carried...	164,884,443	190,506,017	383,402,079	19,562,891	4,362,522	762,717,692
Total number of cars.....	3,247	2,328	6,303	397	129	12,404
Average passengers per car	50,780	81,832	60,828	49,276	33,817	55,307

motors. The population tributary to this road numbers 8973. The number of passengers carried in 1890 was 348,646, or 38.8 times the population. In South Framingham, Mass., with a population of 9239, the passengers carried numbers 337,000, or 36.4 times the population. In larger cities this ratio increases. The Union Street Railway, New Bedford, carried over 79 times its population, and Brockton 62 times, and yet the former has but a population of 40,733 and the latter place 35,681. In the larger cities this ratio again increases. If we include the towns tributary to Boston, we find the ratio of that city is 174.2. Nothing more clearly shows their need than these ratios of patronage. It also shows that in great cities the street railroad is of still greater value and importance. Prof. Lewis Haupt, of Philadelphia, in a most interesting pamphlet in 1888 gives some further most interesting statistics of traffic growth. He shows that, whereas in New York City the increase of the population from 1865 to 1885, a period of 20 years, was but 59 per cent, the growth of the total traffic on all street and elevated lines was for the same period 262 per cent. He also shows that, whereas the increase of the population in London, Eng., for 20 years, 1864 to 1884, was but 36 per cent, the traffic increase was 460 per cent.

Another striking feature is that in 1850 we had no street railroad traffic, while today the passengers carried number somewhere up in the billions, and yet the population of the United States has increased from 23,000,000, in 1850, to 62,000,000, in 1890, or about three times. From nothing to billions in 40 years. Whereas the steam railroad having a record of 60 years has not yet reached half a billion. The passenger traffic per mile of steam line is 3068, but, as near as I can obtain it on the conservative basis, it is over 200,000 per mile of street railroad line. Do not the foregoing figures most vividly illustrate the value of these traveling facilities? Prof. Haupt computes from a few arbitrary units and a few facts in a most interesting and ingenious way that the patronage in Philadelphia per mile of street car line is 434,500 persons per annum. I tried to arrange some comparison on the basis of square miles or acres, but it was impossible to get the areas of the cities or towns in which the street railroads were operating. This, therefore, had to be abandoned. Table V shows the growth of the steam roads and their traffic.

Outside of the passenger traffic comparison I have been unable

to gather anything of any reliability whatever. You will therefore have to judge of the relative value of the steam and street railroads of this country from simply their respective passenger traffic. The value to this country of the transportation of the billions of people on the street railways in a political, physical, and social sense you can judge of as well as I. The steady and enormous increase of the traffic in recent years certainly points to one conclusion. Personally, I am convinced that the future of the street railway traffic has a greater influence upon the prosperity of this nation than almost any other factor.

It is variously estimated that there are from 200 to 225 million of dollars interested in the street railway business. This is insignificant as compared with the seven or eight billions that is interested in the steam railroads. I hope that all the other States will follow the example of Massachusetts, since I feel from the brief study which I have given this question that one of extreme interest and vital importance is before us.

MEETING 415.

The Value of the Study of Modern Languages to a Student of Science.

BY PROF. A. N. VAN DAELL.

The 415th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, April 9th, at 8 P.M., Hon. J. A. Dresser in the chair.

After the reading of the records of the previous meeting, the chairman introduced Prof. A. N. Van Daell, of the Institute, who read a paper on "The Value of the Study of Modern Languages to a Student of Science."

Prof. VAN DAELL said: It is easy to say many things in praise of any study that one may take up. Every branch of knowledge has decided advantages, and in every branch of knowledge, whether it be

of science, of literature, or of philosophy, there is enough of truth and of discipline to engage the mind and attention of all men. Of course, every man can be benefited by any study whatsoever, but this does not indicate the place a study ought to occupy. Therefore, in attempting to give the right place to the modern languages, let us consider the general subject of education. By education I mean here the last part of education, not primary instruction, but the part that will directly prepare a man for his life's work. In that one sense we may call it higher education.

The system in general as it now prevails has been imported into America from Europe, and is the result of the practice of the Middle Ages. Our system of education dates, consequently, from a time when the purpose of education was to benefit two classes, the clergy and the aristocracy,—the clergy first; and many of the mediæval colleges and universities began with a single department, that of Theology, which was then counted the highest point to which the human mind could reach. During the 14th, 15th, 16th, 17th, and 18th centuries education was, as I have said, confined almost entirely to the members of the clergy and the aristocracy, and this was true not only of Roman Catholic countries but also of Protestant countries. For instance, in Belgium we find the great reformer, Marnix de Ste. Aldegonde, in the 16th century, writing a book upon education, in which it is very evident that the only persons for whom he wrote were the members of the nobility. Of course, in those days Latin and Greek literature were taught, but no one thought that those literatures ought to be the main part of the education of merchants, tradesmen, or people who were to go out into the world.

America has inherited her system of colleges from Old England. It was directly imported from that country. A few days ago, walking through the streets of Cambridge, I stopped before the newly erected gate of Harvard College and read thereon an inscription stating that the college had been built for the education of the clergy. I do not remember the exact words, but the main import of it was that the purpose of the foundation of this college was that the clergy should not degenerate from the clergy that had come from Old England, and if you go over the history of your colonies, and the history of the foundation of Amherst and Yale and other colleges, I think you will find the same idea prevailing.

We see, then, that in olden times education was intended for the society where there was an intellectual aristocracy, and that it was designed that a few men should be the guides of the nation and direct it in its intellectual pursuits. Those men were to be looked up to as the leaders of thought, and the leaders not only in religious but in secular affairs. The same, of course, was true of France, of Germany, and of England. In those countries people who did not belong to the nobility, or to the clergy, or to a few privileged bodies, were literally "nobodies." So we must not forget that during the Middle Ages, when they spoke of education, they did not mean the education of the masses, for the masses were never considered. They were not thought of even in the foundation of American colleges. How different our circumstances now! The system based upon those old-fashioned ideas of forming a small aristocracy is, of course, altogether out of keeping with our train of thought, with our ideas, and with the ambition of the present day. Our world is no longer governed by aristocrats or scholars. Aristocracy in the intellectual sense has long since disappeared from Europe even. The cheapening of books and the placing of education at the disposition of the poorer classes have completely destroyed intellectual aristocracy. French civilization during the monarchy and before the Revolution was admirable to look at,—very beautiful, very elegant. Men were trained there for the purpose of shining in society, and of being able to express themselves with elegance.

I need not say that the continuation even in a small degree of the educational ideas of the Middle Ages causes a deep discontent, which is not confined to America. It has been expressed just as loudly, perhaps, in Germany and in France. Years ago this discontent caused in Germany the foundation of the *realschule*, and to a certain extent an equalization was accomplished by the giving of the privileges which had been reserved for the scholars of the university to the pupils of the *realschule*, that is, to students of science. In France the same thing was attempted but not without a struggle. During the Revolution, at one time, the study of Latin and Greek disappeared almost completely from the schools, and was, to a certain extent, replaced by the sciences. Then there was a change, and the ancient languages were restored to their place in the curriculum. Again, expressions of discontent were heard on all sides, and so loud

were they that a division of the course was attempted, but without success. Not enough teachers were imbued with the new ideas and new methods to make them prevail, and up to the present time general scientific instruction has not been equal to the instruction given in the old classical lines. But discontent is not showing itself in institutions alone; it is felt outside in the ranks of society. Formerly, those who had not enjoyed the privileges of a college education were willing to submit to the intellectual government of the scholarly classes. Today the situation is entirely changed. The business man, self-made perhaps, looks down upon the scholar as a kind of unpractical man, hardly fitted for the struggles of this world, or as a kind of weak intellectual product of ages gone by; and the scholar, on his side, in many cases fails to feel the pulse of the modern world, and regards the active man as a kind of inferior creature who has been deprived of many intellectual advantages, and is hardly entitled to give the final word in the great questions of the day. Yet this is an age of activity, progress, and invention, and the hostility to which I have referred is not at all necessary. Our time is not a degenerate one, as many of the old school would say. In the earliest times the same complaints about the degeneracy of the age were heard, and these complaints were repeated through the Middle Ages, and we hear them today as an echo from distant centuries. The truth is we should take our epoch as it is, and should adapt ourselves and our educational system in general to the new conditions.

America, as well as all other countries,—perhaps more than any other country,—is at a period of great productivity. She has advantages over the rest of the world in the vast extent of her territory, her unequaled natural resources, and in her unrestrained liberty; and in the absence of any military obligation, and in the friendly industrial struggle among the nations, these conditions must, in the end, give her victory. Armies cost not only the sums of money that are expended on them, but they are a detriment to a nation, because they engage the best years of the strongest class of men at what ought to be the most active period of life. The amount of labor taken away from every one of the European nations in the years that the strongest and best of their young men spend in armies cannot be estimated in dollars and cents. Besides this, the unrestrained liberty that you enjoy in America is of great importance in that industrial struggle.

Montesquieu, in the 18th century, said : "*Les pays ne sont pas cultivés en raison de leur fertilité, mais en raison de leur liberté,*" — countries are not cultivated in proportion to their fertility but in proportion to their liberty.

Instruction must be directed to useful works. It must be done in the most economical way ; and by economy I mean especially economy of time. We have already seen in another connection that time is much more than money. I take it for granted that you all admit not only the necessity for institutions like this Institute of Technology, but that colleges also must, in future, if they wish to keep their rank, reform their curriculum of studies so as to bring them within the range of modern possibilities. I do not say that everybody ought to follow industrial or scientific pursuits. Of course, scholars, those who are to become teachers, and those who intend to follow the professions in life, ought to be treated differently. But we are speaking now of the education of the masses of a nation, and those masses undoubtedly must be the producers, those that accumulate wealth by their work. And this must bring industrial teaching down to the secondary schools, and even to the primary grade, at least for the nations that wish to be at the head of modern civilization and to gain national prosperity. Now, does this mean that the business man, the manufacturer, the engineer, shall be taught nothing but science, nothing but that which is directly conducive to his success as a business man? That I think is a mistake into which scientific people are apt to fall. They are likely to consider everything a hindrance that takes a student away from scientific pursuits. Let us look at a man who has been successful without having anything of what we may call literary training. As a rule, you will see, I think, that he is unfitted to enjoy the benefits of his prosperity. He may not know how to communicate with other people. He may be so wrapped up in his financial success that nothing else is of any interest to him. He may be just as miserable with his millions as the poorest toiler in one of the large cities. Then, what would be the state of society in which men of that kind ruled and became the dominant class? I venture to say that it would be most undesirable ; that it would gradually return to barbarism ; that it would be the destruction of everything that is good and beautiful ; and that those individuals who concentrate their sole attention, their whole mind and heart, upon business must

finally become egotistical, and, being self-satisfied, will never look for any progress outside of that which would result directly in their own personal benefit. This, of course, must not be; so, by the side of those necessary scientific pursuits, something must be done to raise to a higher intellectual level the young man who looks forward to a scientific and industrial career. He must not only be a business man but a *man*. He must learn to love, to admire, and to reverence not only people of his immediate family, for that might be egotistical, but his country and whatever has been great and noble in it. But even that is not enough. A country wrapped up in itself will soon degenerate. It is a fact that we all need comparison. We cannot understand the greatness of our country unless we compare it with other countries. Nor can we realize the faults of our country, find out what ought to be corrected, what ought to be changed and bettered, unless we study at the same time the history of other countries. We must, then, bring some wider influence to bear upon the young man. He might study art, or he might study literature. The study of art would in some cases have many advantages. A thorough love of art brings with it a great civilizing and humanizing influence; but to teach it, to practice it, is often very difficult. To bring it within the reach of the masses, so as to benefit them and to make them thoroughly enjoy it, is in many cases an almost impossible task. The master-pieces of art may not be at hand; the means for reproducing them may be imperfect; there may be no teachers. Art, then, while it has in itself many humanizing influences, is often practically impossible for educational purposes. There remains literature. Now, what literature shall the young man study? I do not hesitate, of course, to answer, his own literature first, because it is the easiest and most accessible; the one which he will enjoy most and which will consequently most benefit him. The study of the ancient literatures, which is advocated by many in the colleges, and even in schools, as the only really humanizing study, is often impossible for the student of science, primarily because it takes too much time. The study of science requires in itself much time. If we consider the courses here at the Institute, we find that the number of hours given by the young men to study cannot very well be increased, and it should not be; not that I believe they are over-worked; not that I think they have become "mental wrecks," as one of the Boston papers has said; far from that. But

still it is evident to me at least that those among them who give the due amount of attention to their courses are as fully occupied as they ought to be, and an increase in the number of hours is, I think, reasonably out of the question. They ought to study, then, their own literature. But a single literature is not enough, because a thorough comprehension of one literature, and a comprehension of the value of the writers, is almost impossible without comparison, for here again, as in many other fields, comparison is necessary. Among the great literatures of the world it is almost a matter of necessity to choose the great literatures of France and of Germany for educational purposes, because those literatures contain nearly all the works that are a part of the history of the civilization of the world. Those literatures contain, with the English literature, the most valuable works for the study of the sciences. Other literatures, of course, might be taken up, as, for instance, Italian or Spanish literature, but their importance is very secondary if you compare them with English, French, or German. As for French, John Stuart Mill, in his *Essays*, says that "the man who does not know that the history of French civilization is the history of the civilization of the world is very ignorant indeed." And Germany has of late taken so important a part in modern civilization that her language and her literature have now a very great importance. Besides, these two literatures of France and Germany bear directly upon English, and have a close connection with it. They contain a wealth of the most famous writers, and number among them some whose books are immortal and would inspire the student who could read them with a love of the beautiful and of the good. Now it is possible, within the time allowed for the study of these literatures, to make a lasting impression upon the minds of the students, and to arrive at a good result, that is, at a fluent reading of the works written in those languages. And this is not all. We ought to be able to do much more than that if only the preparatory schools would help us. It is by no means difficult to take a young boy of twelve or thirteen years of age, or even much younger than that, say seven or eight, and teach him to read with facility easy books in French and German adapted to his years, and this could be done, I think, without crowding out anything that should remain in the curriculum. If young men came to us thus prepared and possessing already that elementary knowledge of languages, we could then, in institutions like

the Institute of Technology, lead them further on in the study of literature, making a lasting impression upon them, and bringing them into communication with the great minds of the last centuries, with Göthe, with Moliere, with all the classics of the 17th and even the 16th century of France. We could then make them read easily all the important books that are now published in large numbers. There would then be no lack of that love for art and literature which was produced by the study of the ancient classics, for the same thought, the same civilization, or at least analogous civilizations, are repeated in France and Germany, and they are much more accessible on account of the similitude of times. Those civilizations come very near to us, and young men understand them more readily than they do the more remote civilizations of the Greeks and Romans. It is rare even now to find youths coming out of college able to read easily a Latin book. I do not even speak of a Greek book. Very few of these graduates ever think of reading a Latin author. But this is not the experience we have with our French and German authors. A good many readers enjoy them, and remain in communication with the great minds of France and Germany, and I claim that the literary discipline thus acquired is incomparably greater than what is acquired by superficial knowledge of Latin and Greek. I do not, of course, say anything against a thorough study of these languages. If you could bring the youth of the country to understand the value of ancient civilizations, and to compare them with modern civilization, it would undoubtedly be the proper thing to study them in their original languages, but that has never been done since the disappearance of Latin as a spoken language. As for Latin literature, which is so very highly praised by many, it is no more original than French or German or English literature. If one wished to study original literature it would be absolutely necessary to return to Greek and to Greek only; but that, of course, is not possible, mainly because the teachers are not prepared to take up the language in such a practical way, and therefore it is doomed to disappear from the education of the masses. Greek and Latin will be in future the languages studied by scholars and by professional men; but the masses of the nation, the scientific men, those who are intended for the business world and for industrial pursuits, must as a matter of necessity study French and German. These languages are the great resources for the elevation and broadening of the

study of science, and it is on them that we must rely. The main effort now to be made consists in asking more help in the study of these languages; not of the Institute, nor of the curriculum that we have in similar institutions, but of the preparatory schools. If these schools would take away from us the drudgery of elementary instruction in the languages, time would be permitted us to give the students the full benefit that they ought to derive from a thorough acquaintance with French and German civilization.

MEETING 416.

Aluminum and its Bronze.

BY PROF. LEONARD WALDO.

The 416th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, April 23rd, at 8 P.M., Hon. J. A. Dresser in the chair.

After the reading of the records of the previous meeting, the election of new members, and the transaction of routine business, the chairman introduced Prof. Leonard Waldo, of the Aluminum Brass and Bronze Co., of Bridgeport, Conn., who read a paper on "Aluminum and its Bronze."

Owing to our inability to obtain the manuscript of Prof. Waldo's paper it had to be omitted.

MEETING 417.

Recent Improvements in Railroad Signalling.

BY MR. GEO. W. BLODGETT.

The 417th and annual meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, May 14th, at 8 P. M., Mr. Geo. O. Carpenter in the chair.

After the reading of the records of the previous meeting the nominating committee presented their report, and officers were elected for the ensuing year.

The report of the Executive Committee was read and ordered placed upon the records.

Hon. J. A. Dresser then reported on behalf of the meteorological committee.

REPORT OF THE METEOROLOGICAL COMMITTEE.

The committee have continued their occasional visits and interest in the Signal Service Station here during the past year, and note with much satisfaction its improved condition, and the gradually widening scope of its field and methods. The office here continues under the very efficient charge of Sergt. J. W. Smith, of the Signal Corps, who has found no increase of men necessary, seven men with a messenger boy constituting the force. No new instruments have been added, but better facilities have been furnished for printing the daily weather maps. Of these the daily issue for this office is now six hundred, which are sent to every section of New England. This continues to be the largest map issue of any station in the service, and covers more territory than any other. But more interesting still is the fact that more schools and other educational institutions are furnished with weather maps from the Boston office than from all the other stations in the country combined. While they were at first regarded by the public almost as Chinese puzzles, now the demand for them cannot be supplied. Local forecasts are made twice daily at this office, printed on the morning and evening maps, furnished to the local press, and disseminated by the telephone and otherwise. As the Washington

forecasts are generally late, the local predictions only appear most of the time on the morning charts. An interesting feature recently adopted in the maps is the indication of thermal changes or condition of temperature by the use of colors, pink indicating the warmer and blue the cooler condition in the territory thus colored, while a still darker color indicates rain or snow; these indications being much more appreciable by the ordinary observer than isothermal and isobarometric lines.

Numerous instances during the year have illustrated the value of the work of the service. The cranberry growers have acknowledged, by letter to this office, great benefit from the frost warnings furnished them. Gentlemen interested in the production of the smaller fruits and garden products in the south, while resident themselves in Boston, have communicated by telegraph to their managers from this office information and directions of great value. One of our Boston daily papers, commenting editorially upon the value of the warning given of the approach of one of our great storms, remarked that upon that occasion alone it exceeded the entire cost of the service of the whole country for a year.

During the past year the committee have found nothing for which to apply to Washington, and so little either to criticise or to suggest in the conduct of the office that their duties as a committee have been very light, scarcely justifying, certainly not necessitating, their continued official existence, although in correspondence Gen. Greely kindly expressed a desire that a committee should be continued in existence to whom matters might be referred should they arise.

RECENT IMPROVEMENTS IN RAILROAD SIGNALLING.

The chairman then introduced Mr. Geo. W. Blodgett, Electrician of the Boston and Albany Railroad, who read a paper on "Recent Improvements in Railroad Signalling."

Mr. BLODGETT said: Railroad signalling has now become so important and involves so many considerations that it is a well recognized factor in the operation of the largest and best managed railroads, and many of the less important ones, that have not previously paid much attention to this subject, find themselves obliged to enter on its practical consideration.

The earliest application and the most complete development along

the original lines has been in England. Signalling is also more extensively and systematically used in that country than probably anywhere else, but it has received in America a development in another direction more complete than in any other country in the world. This is in the invention of signalling devices to be operated by the trains themselves. All such appliances are known under the name of automatic signals.

The tendency in England has been to meet every new requirement of this branch of business by the use of more men than before. In this country, where labor costs more, the same object has been sought to be accomplished by the invention of a machine to do the work of itself,

The English block system, admirable as it is, and when used with Sykes' locking probably as safe as it is possible to make a signalling device, is yet exceedingly expensive. The cost of construction is enormous; but great as it is the cost of maintenance is a still more serious matter, and is entirely out of reach of the larger part of the railroads of this country. There must be at least a man for day and another for night use, and where there is heavy traffic still another will be needed. In this country these would cost for wages alone from \$1000 to \$2000 per year; or on a road a hundred miles long, equipped with signals every two miles, the wages of signalmen would amount to from \$50,000 to \$100,000 per year, a sum which would be thought extravagantly large by most of the railroads of this country. But an *automatic* signal can be erected for \$500 and maintained for from \$60 to \$100 per year, and this consideration alone, if such a signal can be made reasonably reliable, ought to lead to their adoption by many roads which have hitherto thought that they could not afford any kind of signals.

It is less than twenty-five years since automatic signals began to have any place in railroad service. Mr. Thomas Hall, then of Stamford, Conn., was, I believe, the pioneer in this country, where they have had their greatest development and most practical application. His first invention was for the purpose of showing at a distance whether or not a switch was set for the main line. This was shortly followed by other inventions for indicating to an approaching train whether or not a preceding train had passed a certain point a mile (or any other desired distance) in advance. All these were automatic, that is, operated by the movement of the switch, or the passage of the train, without intervention of a man.

Automatic signals may be divided into two principal groups, viz., those which have for their object the maintenance of a certain interval of *time* between trains, and those which keep a certain interval of *space* between trains following each other on the same track. It seems to me that no time signal can have much positive value, for its indication, even if reliable, only tells us where the train was at a certain previous time, not where it is at present, which is what we want to know. The indications of a time signal are of a misleading character, or at least the inferences drawn from them are frequently so. A trainman will almost certainly assume that a preceding train has been running at its scheduled speed for the whole time which has elapsed since it passed the signal, and is presumably a long distance in advance when in fact it may have come to a standstill just around the next curve. If, however, the signal is so constructed that it remains at danger till the train reaches a certain point in advance, *no matter how long it takes to get there*, then, whatever its faults in other directions, its errors will be on the side of safety, the assumption being that a train is in the section if the signal stands at danger.

Although it has been shown again and again how utterly unreliable an automatic time signal must of necessity be as a protection from following trains, yet hardly a year passes that several people do not invent devices of this character. If the ingenuity and labor which has been spent on this class of inventions had been more wisely employed, it would have produced more valuable and lasting fruit. When the principles of automatic signalling are better understood by railroad men there would seem to be no need of argument to prove that time signals do not sufficiently meet the conditions of the problem.

One of these principles is that —

Automatic signals should be used as an addition to all the other safeguards for the running of trains, and not as a substitute for them. It will therefore be necessary, as heretofore, to send back a flagman when a train stops, but there will be the additional security that when the man neglects his duty, or trains are running near together, there will still be protection, which is ample in the large majority of cases from a collision by a train following on the same track, or on a single track road for both front and rear.

A second principle is that if the normal position of the signal (that is, the position when no train is in the section) is all clear, it

should be produced by the constant application of some positive force, the failure of which for a single instant should cause the danger signal, which danger signal should continue as long as the difficulty, whatever it may be, exists. A signal standing clear for an approaching train will then indicate that not only is there no other train in dangerous proximity, but that the force on which the clear signal depends is in existence and actually at work.

Still another principle, which is in my judgment correct, but which is disputed by some railroad men of as large experience as my own, is that when a train enters a section the engineer should see that the signal actually works for his train, and to this end each signal should go to danger a little before the train passes it. The development of automatic signalling in the last few years has been in the direction of greater safety and simplicity, and the requirement of less force to operate them. One of the most prominent of the systems of automatic signals shown to the Society a few years since when this subject was under consideration is that of the Union Switch & Signal Co. Their apparatus has undergone little change since that time until recently, when a new instrument has been devised which bids fair to be a great improvement over the old one, and removes some of the causes of derangement in that instrument. The new one has a semaphore arm for a signal instead of a revolving disc. The semaphore can be seen probably at a greater distance than a disc, and is very distinct in form. Objection is sometimes made by some railroad men that when the semaphore is used at important points (as at junctions, yards, etc.) as a positive block signal, where it must be obeyed as well as observed, it should not be elsewhere used in another way. The form of signal is not, however, so important a point as how the signals are to be used. In the plan for overlapping blocks of the Union system changes have been made so that a failure of some of the circuits to operate will not, as was formerly sometimes the case, keep the signal from going to the danger position.

The electro-pneumatic signals, which have been invented but a few years, have been recently put in operation on a number of roads. The new Hall system, recently brought before the public, is like the old one only in the form of the disc, viz., a red disc on a revolving arm so arranged as to bring the disc sometimes into view before a window in the signal case, and sometimes to withdraw it out of sight.

This is connected in a closed circuit through a relay, then through a track instrument at the beginning of the section, and every switch connected with that signal and back to the battery. An interruption of this circuit at any point will cause the danger signal to appear; also, when once the circuit through the signal has been interrupted it cannot again be made complete, except by the operation of a track instrument at the end of the section;* further, by the action of another circuit when a train enters the section, even the operation of the circuit which clears the signal will have no effect until the train has first operated another track instrument located a little way from the end of the section. This is to protect against a train sometimes producing a clear signal behind another train in the section, as formerly would have been the case under certain circumstances. When the train has gone a little way into the section, by means of a track instrument at that point, it so arranges the circuits that if a second train should follow the first into the section, the first one in passing out of the section could not put the signal clear, but it would restore the circuits so that the second train could clear the signal when it left the section. If only one train is in the section it leaves the signal clear when it passes out. These several operations are performed by a peculiar form of relay known as a double-circuit instrument. To keep trains a proper distance apart, the track instrument which puts a signal clear is located some definite distance (known as the "overlap") beyond the next signal, if they are used in series as is usually the case. The operation is the same for any number of trains in a section at the same time, provided they keep a train length apart, only the last train putting the signal clear when it leaves the section.

A system of signals was recently described to me which is so designed that when a train enters a section it sets a danger signal, and each pair of wheels entering the section is automatically registered there, and the signal will not go to the all-clear position until as many pair of wheels go out of the section as entered it. The inventor calls it a "debit and credit" system. If a train enters a section and it leaves part of its cars on a siding, by so doing as many wheels are taken off the account as have been left behind, and the remainder are registered from the end of the section. I have not seen the system in operation and do not know how successful it is in practice.

* In the switches it is provided that when a train has been put on a siding, and the switch replaced on the main line, the signal may be cleared by a hand instrument.

Long's Electric Semaphore is supplied with current generated by a magneto-electric machine, and therefore needs no battery. When used as an automatic train signal, this machine is operated by clock-work set in motion by the wheels of the train; but when used as a yard signal the generator is worked by hand. Used as a yard or station signal where there are trains in both directions, there are two signals, one at each end of the portion of the track in use, so connected together that only one can be put clear at the same time (if properly used). Each signal, when it is put in the all-clear position, automatically cuts off the currents both from itself and the other signal. Before anything further can be done it is necessary to put back to danger the signal which has been set clear, when the other may be set clear if desired. In interlocking signalling the recent changes have been principally in the direction of saving levers and connections. One device coming into extensive use for that purpose is an indicator connected with a semaphore, which does service for many different tracks, the one to which the signal at the moment applies being shown by a letter or number appearing below the signal when it is drawn clear. A somewhat newer device is known as a selector. This is connected with the interlocking machine, and determines which one of a group of signals, all connected with the same lever, shall show clear; and which one will go clear depends on the position of the switches in the different tracks to which the signals apply. These selectors are of two kinds, mechanical and electric. The former answer well for cases where the distances are short, but the latter are practically independent of the distance, and can therefore be used where the others would not be serviceable.

The safety of even interlocking signals is largely increased under certain circumstances by electric locks applied to certain of the levers in one of two ways; 1st, when a train has been given a right to proceed the signal is locked all-clear and cannot be put back to danger till the train has gone past and unlocked it from the other side. This is, in my judgment, a bad use of an excellent principle. It may sometimes be necessary to suddenly put a signal to danger and stop a train after it has been given the right to proceed, and has even begun to use that right. It should therefore always be in the power of the signalman to do this. Hence, no device should ever be applied to an interlocking signal to lock it in the all-clear position. But electric

locking is an extremely valuable safeguard if used in the other way of which I spoke, viz., 2nd, to lock electrically every conflicting route by the presence of the train on the track. In these last-named applications the simultaneous occurrence of two things is necessary in order that the locks may apply, viz., the giving of a clear signal, and the presence of a train on the track. Hence, up to the moment when the train has arrived, the signalman is free to take away a permission he may have given for the train to proceed; but when it has begun to occupy the right of way, the signalman is powerless to interfere with its passage in safety, but he may, if it be necessary, put the signal to danger and stop the train, but can do no more. This is a most satisfactory method of using electric locks, because of its extreme convenience and flexibility. The signalman is absolutely free until the moment when it would be unsafe for him to be so, and the restriction applies as long as the danger continues, viz., until the last pair of wheels has left the section.

A new form of signal, for a new purpose, is that known as the Stewart-Hall Train Order Signal. It is for the purpose of reminding an operator or agent at a station that he holds an order for a train which is to arrive at that station. It consists of an out-of-door signal, so connected with a relay in the office that on receipt of an order, which the operator is to put in a box where the trainmen are to look, or where he himself is to go when the train arrives. In doing this the out-of-door signal is set at danger, and the circuit which puts it clear is broken, so that it cannot be got clear again until the operator has gone to the other side of the room, or some other rather distant place, so that he cannot carelessly or accidentally put the signal clear (or do so thoughtlessly), and the train cannot proceed until he has cleared the signal. Thus, from the smallest beginnings these signaling devices (valuable auxiliaries to the safe operation of a railroad) have grown to occupy a very prominent place, and in the near future will be thought second to none in importance for securing this result.

MEETING 418.

*Manganese Steel.*BY MR. HENRY M. HOWE.

*The State Board of Health Map of Normal Chlorine in the Waters of
Massachusetts.*BY PROF. THOMAS M. DROWN.

The 418th meeting of the SOCIETY OF ARTS was held at the Institute on Thursday, May 28th, at 8 P.M., Mr. George W. Blodgett in the chair.

After the reading of the records of the previous meeting, and the election of new members, the chairman introduced Mr. Henry M. Howe, of Boston, who read a paper on "Manganese Steel."

Mr. Howe said: Manganese steel is an alloy of iron and manganese. We can hardly call a substance steel which is not malleable. Alloys of iron with more than 20 per cent of manganese are not malleable and must be classed rather as manganiferous cast-iron, or ferro-manganese. Alloys of iron with less than about 3.5 per cent of manganese are not profoundly affected by the manganese which they contain, and can therefore hardly be called manganese steel. Manganese steel, then, is an alloy of iron with from about 3.5 to about 20 per cent of manganese. It always incidentally contains more or less carbon, and we now know no way of introducing the manganese without simultaneously introducing carbon as well.

The influence of increasing quantities of manganese on the properties of iron is most remarkable. The elongation is very small when the alloy contains $6\frac{1}{2}$ per cent of manganese, or less. Indeed, with from about 4 to about 6.5 per cent of manganese the alloy has practically no elongation. It is so brittle that it can be pulverized like glass. I will not say that methods of remedying this brittleness may not later be devised.

As the proportion of manganese rises above 7 per cent, a most remarkable increase in both elongation and strength occurs, the elon-

gation almost leaping from 2 to 50 per cent, while the tensile strength increases from about 50,000 to nearly 150,000 pounds per square inch. With further increase of manganese the elongation diminishes as abruptly as it rose, while the tensile strength as well falls rapidly. With 20 per cent of manganese we again reach an extremely brittle alloy, valueless as far as we now know. This great ductility and strength are given to the metal by special treatment. In its natural state, as when it has cooled slowly after forging, manganese steel is decidedly brittle and not particularly strong. As we all know, common steel is made so hard that it will scratch glass, and almost as brittle as that glass by sudden cooling from a bright red heat, for instance, by quenching in cold water; while it is made soft, relatively weak and ductile, by slowly cooling it from a red heat. With manganese steel the very opposite is true. When slowly cooled from redness it is brittle. Its extraordinary toughness and strength are given it by quenching it in water when at bright redness. They are again lost if it be subsequently strongly heated; but they may be reacquired by again suddenly cooling from bright redness. The more sudden the cooling the stronger and tougher the steel.

Remarkable as are the ductility and strength of manganese steel, they alone would give it little value, for we can obtain this combination in other and kindlier materials. It is its unique combination of hardness with ductility and toughness that gives it its value in the arts. Hardness and brittleness habitually go hand in hand, so much so that they are associated in our minds as necessarily co-existent. All our hard substances, minerals, glass, hardened steel, are brittle. With the possible exception of nickel steel, as to which our knowledge is extremely scanty, manganese steel is the only substance within my knowledge which is at once hard and ductile. When tested for its resistance to abrasion, where manganese steel lost one part by weight tempered tool steel lost about 0.4 parts. Manganese steel is thus decidedly softer than tempered tool steel, but the latter is far too brittle to compete with manganese steel in the uses which demand ductility and power to resist severe shock. Annealed tool steel lost 7.5; hardened boiler-plate steel lost 7; and annealed boiler-plate steel 14 parts by weight.

But while its hardness gives manganese steel its value, it also forms the chief obstacle to its use, for it deprives us of the readiest

way of shaping it. The other materials which the engineer uses are readily cut by common hardened steel. The metals are brought roughly to shape while hot, soft, and plastic, and are then accurately fitted by cutting with steel tools.

Manganese steel cannot, by any known means, be made soft while cold. It always remains so hard that it is extremely difficult to cut it with steel tools. We can, indeed, readily give it simple shapes, such as that of a plain round or square bar, while it is hot. Unfortunately, such pieces have but scanty use in the arts. This one must have a thread; that one must have a hole here, a shoulder there.

Fortunately, manganese steel can be worked comparatively readily while hot, though, indeed, decidedly less readily than common steel. A given blow changes its shape much less than that of common steel. In short, even when hot, manganese steel is still harder than common steel. Fortunately, too, the last few years have brought great developments in the shaping of metals while hot. We have important advances in drop-forging and in hydraulic forging, while the Symonds Rolling Machines, and several others less known to the public, but still of great promise, lessen the disadvantage which the persistent hardness of manganese steel raises to its use.

Hard as it is, manganese steel can yet be worked cold to a considerable extent, as is shown by this small wire. Such thin wire could hardly be made while hot, and, actually, it has been drawn cold in the common way. But, ductile as it is when we measure ductility by elongation, it does not draw into wire readily. After every two drafts it must be annealed by heating to bright redness and quenching in cold water. While it is thus possible to make manganese steel wire, I do not look to see this or any like form of cold-working extensively used in shaping this alloy. More applicable to it is Mr. Samuel Johnston's machine, which can roll even this hard metal while cold into remarkably irregular shapes. Without describing this machine, I may say that just as we can turn wood into gun stocks and axe handles, so can we make such irregular shapes with this machine from even hard metals. But the most promising means of shaping manganese steel cold is the emery wheel. It is to manganese steel what the steel tool is to other metals. Just as we cut iron in lathe or planer by moving it past a stationary tool of hardened steel, so may we cut manganese steel by moving it against and past a swiftly revolving emery wheel.

Let us now notice briefly a few of the more striking properties of manganese steel. Its electric conductivity is extremely low, about one-thirtieth that of copper, and one-eighth that of wrought iron; but it is extremely constant under varying temperature, about thrice as constant as that of iron. Its conductivity for heat is also extremely low, a fact which has to be allowed for in forging it. It welds with extreme difficulty, even in Thomson's electric welding apparatus. This difficulty further restricts its use.

The structure of an ingot of manganese steel differs markedly from the coarsely crystalline structure of one of common steel, and consists of a mass of coarse needles arranged at right angles to the cooling surface. The coarse structure of carbon steel castings is broken up by simply heating and cooling them, whether quickly or slowly. That of manganese steel does not appear to be changed by simply change of temperature, but it is completely changed by forging.

Manganese steel is not attracted by the magnet. This may possibly give it a value in marine construction, or at least in the case of compasses, of electrical machinery, and of watches.

The most important single use of manganese steel is for the pins of elevator dredgers, such as are shown in this photograph. These dredgers have a series of enormous buckets like those of a Brobdignagian grain elevator. The pins on which these buckets hang must be very strong and tough, and yet hard, as they are constantly grinding the grit which surrounds them against the links which hold them. This photograph shows the condition of a manganese steel pin after it had been used more than thrice as long as the carbon-steel pin beside it. To judge from this photograph, the manganese steel would wear about ten times as long as the carbon-steel pin. For this purpose manganese steel has been regularly adopted, as I understand, and has passed beyond the experimental state. The lips of many dredger buckets have also been made of manganese steel, and so have the links of small elevators, such as are used for grain. Here are some of these links, simple castings, their toughness being shown by the distortion they have undergone.

The great future for manganese steel seems to be its use for car wheels. A car wheel should be tough, lest it break; it must be hard, lest it wear out, the friction of brake-shoe against wheel being very severe. Manganese steel wheels on the Chester Tramway in England

were removed after running 80,000 miles. The average mileage of cast-iron wheels of two well-known brands on a street railway in a large Eastern city was given me last autumn as 7748 miles in one case, and 16,373 miles in another. The mileage of street-car wheels is much less than that of steam-railroad wheels, because street-car wheels are comparatively small; because the brakes are applied to them so often; and probably also because they are so much exposed to grit.

Manganese steel also promises well as a material for armor plates. Wrought iron is out of the race, because it is so soft that a shot pierces it easily. Common steel, if it is hard enough to stop the shot, is very liable to crack when struck, and thus to let water in. Manganese steel promises to be hard enough to stop the shot, yet tough enough not to be cracked by the impact. This sketch shows the actual effect of the impact of shot on wrought iron, on common steel, and on manganese steel. The wrought iron was completely perforated; the common steel stopped the shot but was cracked through, the point of the shot knocking a hole through it; the manganese steel plate was a little dished, but, though the point of the shot passed half way through it, only very slight surface cracks were formed.

To sum up, the advantage offered by manganese steel is its probably unique combination of hardness with ductility and safety under shock. Its disadvantage is the first cost of the material, which may be about 0.5 cents per pound more than that of common steel, though much less than the cost of the better class of tool steel; the rather greater difficulty of working it when hot; and the much greater difficulty of working it when cold.

THE STATE BOARD OF HEALTH MAP OF NORMAL CHLORINE IN THE WATERS OF MASSACHUSETTS.

At the conclusion of Mr. Howe's paper the chairman introduced Prof. Thomas M. Drown, of the Institute, who read a paper on "The State Board of Health Map of Normal Chlorine in the Waters of Massachusetts."*

Prof. DROWN said: From the standpoint of the public health,

* Compiled from the author's article in the *Report of the Massachusetts State Board of Health on Water Supply and Sewerage*, 1890.

the natural classification of waters is into those which have at no time been contaminated by the waste products of human life, and those which have been thus contaminated. Waters of the first class we call *normal*. In the latter class we attempt to express the amount of polluting matter of the nature of sewage which the water has received, by giving its variation from the normal chlorine contents of the region.

A comparison of the determinations of the chlorine in the waters of the State, made during the past two years, shows the interesting fact that there is a regular decrease in amount as we go from the seaboard westward. By selecting waters near their source, which we know from actual inspection are far removed from all sources of contamination, we are able to establish for many localities the *normal chlorine*. These results, when placed upon a map of Massachusetts, give us a convenient method of determining at a glance what is the chlorine contents of the normal waters of the state. The value of the map is still farther increased by connecting the points of like chlorine contents by lines which can be appropriately called *isochlors*. On the map which has been recently published by the State Board of Health these isochlors represent 0.05 parts of chlorine per 100,000. In the eastern part of the state they are close together, approximately parallel, and conform, in a general way, to the coast line. As we recede from the coast westward the isochlors are wider apart and their parallelism is less marked.

In classifying the waters of the state we use this map as the basis,—that is to say, when the average chlorine contents of a water agree with the isochlors on the map, the water is considered normal. When the amount of chlorine is in excess of the normal, the amount of this excess expresses the extent to which the water is believed to have been polluted. This use of the map of normal chlorine we find justified in most of the cases where we have an accurate knowledge of the water shed. In other words, we find the excess of chlorine in the water to be in proportion to the population on the drainage area.

There are no data in this country sufficiently complete from which we can determine the amount of chlorine contributed to sewage by each inhabitant per day. Calculations based on the volume of sewage per inhabitant in London, and determinations of the amount of chlorine in the sewage and in the water supply, indicate that the amount of chlorine per person per day is 0.045 pound. The average

daily flow of the Sudbury River per square mile of drainage area for the past eleven years is 8,500,000 pounds of water per day. Assuming the data derived from London sewage to be generally applicable, we find that it requires nineteen persons per square mile to increase the chlorine in the water flowing from a drainage area of the size of Sudbury River .01 of a part per 100,000.

Another way of arriving at the population required to produce this result is to divide the population per square mile of watersheds in Massachusetts by the corresponding excess of chlorine in the water. In this way we find, from an average of observations of fifteen streams and reservoirs, that it requires twenty-one persons per square mile to increase the chlorine .01. Observations of nine other streams, where a portion of the chlorine is probably due to manufacturing wastes, give but thirteen inhabitants per .01 increase of chlorine. There are a few streams where the amount of chlorine furnished by manufacturing is still greater, so that each .01 of chlorine corresponds to a still smaller population, the minimum number found being 2.8 persons per square mile. All the foregoing results are based upon averages for a year or more. In the summer, when the flow is small, the population corresponding to .01 excess of chlorine is much smaller, the average of several observations upon streams being seven persons per square mile.

The average results obtained from analyses of ponds should be somewhat larger than those of streams; but the individual results vary so much that it is unnecessary to consider a refinement of this kind. We may say, in a general way, that four families, or 20 persons per square mile, will add, on an average, .01 of a part per 100,000 of chlorine to the water flowing from this area, and that a much smaller population will have the same effect during seasons of low flow.

While we feel confident in the general correctness of the application of the map for the determination of the degree to which the waters have been polluted, it is important that the limitations of its use be clearly understood. Some of these limitations are:—

1. Those waters have been called normal, and have been used in establishing the isochlors, which drain areas believed to be nearly or quite free from population. Until a careful survey of the State be made, with the express object in view of determining the relation of population to the surface and ground waters, we cannot be sure in all

